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U.S. Dairy Industry at a Crossroad: Biotechnology and Policy Choices

CONGRESS OF THE UNITED STATES
OFFICE OF TECHNOLOGY ASSESSMENT

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Foreword

In the 1990s the U.S. dairy industry will experience a technological revolution that will place the industry at a crossroad. This industry will be the first to experience the biotechnology era in American agriculture. New animal health, reproduction, and food processing technologies are being developed. Advanced scientific techniques will be used to produce transgenic animals. These technologies can be used to increase milk production, improve the efficiency of food processing, develop new milk products, increase herd quality, and improve animal health.

Many of the new technologies may create some controversy. But in the early 1990s, the most pervasive and controversial technology will be bovine somatotropin (bST) produced through recombinant DNA technology. Research has shown that the annual gain in milk output per cow from bST would take 10 to 20 years to achieve using current breeding methods. The technology is presently under review by the Food and Drug Administration. Public concerns have been raised about recombinantly derived bST that include the safety to humans of dairy products produced from bST-supplemented cows, the safety of the technology to the animal, and the economic consequences for many dairy farm operators in this country. Some States have placed a moratorium on the use of this technology, even if approved by FDA, and some large retail food chains have refused to sell milk and dairy products from bST test herds even though FDA has approved their sale.

Congress requested the Office of Technology Assessment to examine the emerging technologies that will potentially be available to the dairy industry in the 1990s. This Report analyzes these technologies with special attention to bST. The analysis includes an assessment of bST, a discussion of other emerging technologies in this decade, and an economic and policy analysis of the impact that these technologies, including bST, will have on the dairy industry.

The report concludes that, based on today's research findings, bST poses no additional risk to consumers and does not produce adverse health effects to cows. However, if approved by FDA, bST will accelerate trends that already put additional economic stress on dairy farm operators in many areas of the country. Other new technologies that may become available during the decade may also have similar impacts as bST and raise similar issues. The industry in the decade of the 1990s will be at a crossroad with important decisions concerning new technologies and public policies.

This report was requested as part of a larger study examining emerging agricultural technologies and related issues for the 1990s. The study was requested by the Senate Committee on Agriculture, Nutrition, and Forestry, the House Committee on Government Operations, and the House Committee on Agriculture. The first report issued from this study was *Agricultural Research and Technology Transfer Policies for the 1990s*. Two remaining reports are in progress. Findings from this report are relevant to specific legislation regarding dairy policy that was debated for the 1990 Farm Bill. The information contained in this report was made available to Congress for that debate.

OTA appreciates the support this effort received from the contributions of many individuals. In particular, we are grateful to workshop participants, contractors, reviewers, and informal advisers who provided invaluable assistance in analyzing the issues on this subject. OTA, however, remains solely responsible for the contents of this report.

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[1] From September through December 1990

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Chapter 1

Summary

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Chapter 1
Summary

The dairy industry will lead U.S. agriculture into the biotechnology era of the 1990s, and also will feel the first profound impacts of emerging technologies. Recombinant DNA techniques, cell culture and antibody methods are but a few of the new biotechnology techniques that will produce technologies that will sustain or accelerate the historical 2-percent annual increase in milk output per cow.

Whereas farmers once had no choice but to pasture bulls with cows and let nature run its course, artificial insemination has provided a means of controlled breeding since about 1950. In the near future, farmers will potentially exercise even more control over herd reproduction and genetics and over the health and milk-producing potential of their animals. For example, embryos produced by in vitro fertilization (of ova from selected females with sexed sperm) and placed at predetermined times into the uteri of estrous-cycled animals can result in higher conception rates than are now obtained by artificial insemination. This will accelerate genetic gains. Monoclonal antibodies used as diagnostic agents will greatly reduce the cost, time, and labor required to maintain animal health. Bovine somatotropin produced with recombinant DNA technologies has the potential to greatly enhance milk production per cow.

The emerging biotechnologies will require considerable management expertise on the part of farmers. Information technologies will be powerful aids to farm operators. Expert systems, for example, make onfarm consulting accessible via a microcomputer and can aid farmers with decisions regarding management and new technology adoption.

Many biotechnologies will be controversial, most notably bovine somatotropin (bST). Although bST can boost milk yield per cow significantly—doing in 1 year what it would take 10 to 20 years to achieve with current reproductive technologies, concerns have been raised about its safety for humans and animals and about the economic consequences of its use for the industry. In response to these concerns, two States placed a moratorium on the use of bST if approved by the Food and Drug Administration (FDA); up to four States are seriously considering laws that would require milk and dairy products produced from bST-supplemented cows to be so labeled. Major retail food chains have curtailed sales of milk and dairy products from bST test herds even though FDA has approved their sale.

In addition, issues concerning science policy have been raised in conjunction with biotechnology—including bST. These issues include the social needs being met by these new technologies, the appropriateness of public sector investment in their development, and lack of information about benefits and risks of a new technology prior to commercialization. This report analyzes the major questions concerning the use and safety of bST, examines other technologies that will affect the dairy industry in this decade, and evaluates the economic and policy implications of these issues.

AN EMERGING TECHNOLOGY: BOVINE SOMATOTROPIN (bST)

Some 50 years ago, research showed increased growth rates in rats injected with a crude pituitary extract. Later it was discovered that the extract, which contains a protein hormone called somatotropin, also affects lactation, and research with lactating cows ensued. Prior to the 1980s, progress was slow in bST research because: 1) the availability of bST was restricted to that which could be extracted from pituitary glands of slaughtered animals, limiting studies to a few cows and short timeframes; and 2) the mechanism of action for bST was thought to be acutely stimulated use of body fat reserves: scientists believed it would only work in fat cows with a low milk yield. No studies used high milk-producing cows because it was assumed that acute mobilization of body fat reserves would cause ketosis[1] and other adverse health effects.

In the late 1970s, new research showed that the physiological basis for more efficient milk production in genetically superior cows was better use of absorbed nutrients. Scientists recognized the need for new concepts regarding nutrient regulation in animals. Recent work has demonstrated that somatotropin exerts key control over nutrient use. When administered exogenously, bST markedly improves productive efficiency in lactating cows. In the last decade, as the important role of somatotropin has been established, bST produced by recombinant DNA technology has replaced pituitary-derived bST in research with cows. Since that time, the quantity and scope of the research with bST has increased exponentially.

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[1] A metabolic disorder which occurs when production of ketones exceeds the ability of the body to use them. Occurs in dairy cows when the need for glucose exceeds the production of glucose.

Production Response

The impact of bST on milk production will vary according to quality of management on individual farms, but a reasonable expectation is that successful adopters would experience, on average, a 12-percent boost in production. However, the increase in output per cow tends to be absolute (in number of pounds) rather than proportional to normal production. Thus, approximately the same increase in pounds of milk produced might be expected (in comparably managed herds) from all cows producing 12,000 to 20,000 pounds of milk per year. Supplementation with bST not only results in an immediate increase in milk yield, it also reduces the normal decline in milk yield during the lactation period.

Because bST is rapidly cleared from the bloodstream and is not stored in the body, exogenous bST is needed every day to sustain the increase in milk yield. This requires daily injections or use of a prolonged release formulation of bST. Several prolonged release formulations have been developed and are administered by subcutaneous injection at intervals ranging from 2 or 4 weeks.

Obtaining a milk response to bST does not require special diets or unusual feed ingredients. Substantial milk responses have been observed on diets ranging from pasture to the more typical forage/concentrate diets used in the United States. However, voluntary intake of feed increases in bST-supplemented dairy cows. This increase in voluntary intake occurs after a few weeks of bST supplementation and persists throughout the interval of bST use. It has been consistently observed across a wide range of diets.

Poor management results in a near zero response from bST supplement. Facets that contribute to the quality of management (and milk response to bST) include the herd health program, milking practices, nutrition program, and environmental conditions.

Food Safety Considerations

Somatotropin is produced by the anterior pituitary gland and is transported by the blood to various body organs where it has certain biological effects. If somatotropin is given orally it is broken down to its constituent amino acids in the digestive process just like any other dietary protein. Thus, somatotropin must be injected to be biologically active.

Somatotropin is species-limited, and the biological effects of somatotropin from one species on others varies. In order to have any biological effect, a protein hormone first must bind to a specific cell-surface receptor. Studies have shown conclusively that due to its unique three-dimensional shape, bST does not elicit any of its normal biological actions in humans even if injected.

Recombinantly derived bST products may differ slightly from the bST produced by the pituitary gland because in the manufacturing process a few extra amino acids can become attached at the end of the bST molecule. The number of extra amino acids varies from one to eight depending on the particular manufacturing process. Some manufacturing processes produce no additional amino acids. The additional amino acids that may be produced do not change the three-dimensional shape of the active part of the molecule and, hence, do not alter the biological activity of bST in dairy cows or the lack of activity of bST in humans.

Some biological actions of somatotropin in cows may be mediated by insulin-like growth factor 1 (IGF-1). This protein hormone, a member of the somatomedian family, normally occurs in trace levels in milk and also in human saliva. Administration of bST to dairy cows augments IGF-1 in milk, but the levels are still within the range typically observed in early lactation of untreated cows. Similar to results with bST, studies with laboratory animal models have demonstrated that IGF-1 has no biological activity if administered orally. The importance of increased amounts of IGF-I in milk from bST-treated animals is uncertain. However, the amount of IGF-I ingested in 1 liter of milk approximates the amount of IGF-I in saliva swallowed daily by adults.

Effect on Milk and Meat Composition

The overall composition of milk (fat, protein, and lactose content) and meat is not substantially altered by bST supplementation. There can be minor changes, primarily in fat content of milk during the first few weeks of bST supplementation as the cow's metabolism and voluntary feed intake adjust. However, these changes are temporary and within the standard variation that occurs naturally during a lactation cycle. The meat derived from treated cows has a lower fat content but is otherwise identical.

In manufacturing characteristics, milk from bST-supplemented cows does not differ from the milk of untreated cows. Characteristics that have been evaluated include freezing point, pH, alcohol stability, thermal properties, susceptibility to oxidation, and sensory characteristics, including flavor. Similarly, no differences were observed in cheesemaking properties, including starter culture growth, coagulation, and acidification or in the yield, composition, or sensory properties of various cheeses.

Effects on Bovine Reproductive Performance

Of special interest are bST effects on reproductive variables such as conception rate (services per conception), pregnancy rate (proportion of cows becoming pregnant), and days open (days from parturition to conception). As expected, cows administered bST show decreased pregnancy rates and increased days open; these changes are associated with increases in milk yield and occur regardless of whether or not the high milk yields are achieved using bST. The management of the reproduction cycle may need to be adjusted to account for these physiological changes. Conception rate is unchanged by bST supplementation.

Effect on Bovine Health and Stress

Catastrophic effects such as the incidence of ketosis (underproduction of glucose), fatty liver, crippling lameness, milk fever (feverish disorder following parturition), mastitis (inflammation of the udder), sickness, suffering, and death have been postulated to occur with bST. However, no such effects have been observed with bST-supplementation of dairy cows in any scientifically valid published studies, nor have subtler health effects been in evidence. From the hundreds of investigations with bST, no study reported the lower milk yield and decreased productive efficiency likely to be associated with increased sickness and suffering. Relevant studies include short- and long-term research and both chronic and acute toxicity studies. In acute toxicity studies, dairy cows were given 30,000 mg of bST over a 2-week period, an amount of bST approximately equaling what would be administered in four lactation cycles.

Reduced resistance to infections has not been found to occur in bST supplemented dairy cows although such an effect has also been postulated. Indeed, basic biological studies have demonstrated that rather than reducing resistance to infection, somatotropin plays a key role in several aspects of maintaining immune competence.

Animal stress is more difficult to evaluate than disease, but several indices exist that demonstrate no stress effects due to bST supplementation. Dairy cows would be expected to produce less milk and to be less efficient if they are stressed. Several hundred studies utilizing bST demonstrate increased milk yield and productive efficiency. Studies have also clearly demonstrated that bST has no effect on the energy expended (as heat) for maintenance or for efficiency of milk synthesis.

Commercial Introduction

The FDA must approve bST before it can be sold legally in the United States. Each company seeking FDA approval to market bST must demonstrate that its product is effective (does what the company claims) and safe. The safety evaluation involves three areas:

1. safety of the animal-food products for humans,
2. safety of the bST-supplement to the target animals, and
3. safety of using bST in the environment.

In addition, FDA requires that each company prove that its manufacturing process can produce bST to consistent and acceptable quality standards.

FDA has determined that sufficient scientific information exists to indicate that the milk and meat from bST-supplemented cows is safe for human consumption, and has allowed for these animal products to be marketed from the test herds during the remainder of the investigational period.

In addition to the United States, many countries are reviewing bST for commercial use. In all countries where bST studies are being conducted, the appropriate regulatory agencies have completed the human safety evaluations and without exception, have found it safe for human consumption.

Product Labeling

Some States are considering requiring all food products derived from the milk of bST-supplemented cows to be labeled as such in the marketplace. The basis for labeling seems to relate to a concern about the safety of the products for human consumption. At least two considerations need to be addressed.

First, is the scientific merit or basis for labeling. If there is a valid safety concern, then the food should *not* be marketed for human consumption. Labeling is not the appropriate method for handling a food safety concern. If the regulatory system to evaluate food safety is inadequate, then the system should be changed. Labeling does not excuse the inadequacy.

The second consideration is verification. An effective labeling program requires development and adoption of appropriate regulations and the establishment and funding of a system for implementation and verification. In the case of bST, no known test or technology exist that could be used to distinguish milk from bST-supplemented cows from milk from non-treated cows. Indeed, no change in milk composition as a result of bST supplementation was found in FDA's human safety evaluations.

OTHER EMERGING TECHNOLOGIES

There are a number of emerging technologies that will have a significant influence on the dairy industry in the 1990s in addition to bST. Advances in animal reproduction, animal health, and food processing are occurring, and many of the new technologies being developed use highly sophisticated and complex biotechnology methods. By comparison, the biotechnology methods used to produce bST are rather rudimentary; potentially some of these new technologies could make bST obsolete.

Animal reproduction technologies are advancing rapidly. Researchers have significantly improved their understanding of egg development in the ovary, how to stimulate the release of numerous eggs at once, and how to enhance the development and fertilization of eggs outside of the cow. Embryos can be frozen for later use. Both embryos and sperm can be sexed. It is possible to create multiple copies of an embryo, each of which can be transplanted into a cow whose reproductive cycle has been adjusted to be able to accept the embryo and carry it to term. These new technologies make it possible to improve herd quality more rapidly than can be achieved using traditional breeding methods.

It is possible to create transgenic cattle,[2] however, the techniques currently used are inefficient and require the use of thousands of eggs to produce one transgenic animal. These inefficiencies make it too expensive to produce and market transgenic livestock commercially. However, scientific breakthroughs are leading to the development of technologies that will improve the efficiency of transgenic animal production and substantially lower the cost of doing so. Transgenic livestock may become commercially available in small numbers by the end of the decade.

BST potentially could be supplanted by the development of transgenic cattle. Dairy cows can be developed to produce higher levels of bST so that daily injections or timed release formulations are no longer needed. Alternatively, genes that code for chemicals that suppress bST production can be altered in the cow such that a cow's normal bST production will increase.

New biotechnology products are also being developed to improve animal health. Products include new vaccines and diagnostic kits, as well as compounds that enhance an animal's ability to fight disease.

Not only are new biotechnology products being developed for use in livestock production, but they are also being developed for use in food processing. New products will improve the production of milk products such as cheese and yogurt. They can also be used to detect milk contaminants.

Effective use of these new technologies will place a premium on management skills. New information technologies are being developed to aid farm management. These new technologies can incorporate individual farm data, with pertinent information from national databases, into computer programs that will aid farmers in the decisionmaking process.

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[2] Animals whose hereditary DNA has been augmented by the addition of DNA from a source other than parental germplasm using recombinant DNA techniques.

These new technologies are in various stages of development. Some, such as embryo transfer, recombinant DNA vaccines, and information technologies are already available commercially or will be soon. Other technologies, such as transgenic cattle and advanced reproductive technologies, will not be available until the end of the decade. The collective effect these emerging technologies, including bST, will have on the economic and policy environment of the 1990s is examined next.

ECONOMIC AND POLICY IMPACTS

Dairy Industry Trends

Before discussing the economic and policy impacts that emerging technologies discussed above have on the dairy industry, it is important to consider the major economic trends already at work within the industry. Milk output per cow has been increasing at a very steady rate for many years. Output per cow has grown more rapidly than milk consumption per capita, resulting in a gradual trend toward reduced cow numbers.

Changes in output per cow vary regionally. The Pacific region's output per cow has been about 30 percent higher than the national average and 50 percent higher than that of the lowest producing region. Climatic conditions contribute to some of these differences, but the main factors seem to be related to progressiveness, philosophy, and quality of management demonstrated by different dairy farmers. These factors directly impact technology adoption and the size of dairy farms. Generally, larger dairy farms experience lower production costs. The Pacific Coast and Florida lead the Nation with herd sizes in the 500- to 1,500-cow range. The traditional milk producing regions of the Upper Midwest and Northeast are typically in the 50- to 150-cow range.

There is a corresponding variation in regional profits. The Pacific and Southeast regions realized favorable returns in 1988 ($1.05 per cwt and $1.94 per cwt, respectively) whereas the Upper Midwest and Corn Belt regions had negative returns (–$0.62 per cwt and –$0.18 per cwt, respectively). Returns in the early months of 1991, however, are less favorable in all regions. Farm milk prices have declined significantly from January through March and are expected to fall by 15 to 20 percent for the year compared to 1990. Dairy farms in the traditional milk producing regions are expected to lose considerable equity under these conditions. Pacific and Southeast farms, although still profitable, are expected to operate much closer to their respective break-even points.

These differences have led to shifts in production patterns. The largest increases in milk production have been in the Pacific region where marketings have risen by nearly 40 percent. The traditional Upper Midwest and Northeast regions have each increased milk production about 5 percent. These traditional regions produce about half of the Nation's milk supply and will continue to be a major force in the dairy industry. But if the Upper Midwest and Northeast regions are to maintain their roles as the "dairy States," major changes in scale of operation, progressiveness in technology adoption, philosophy, and quality of management and perhaps dairy policy may be required.

Technology Adoption

When emerging technologies, such as bST, become available commercially it is not known with any degree of certainty how many dairy farmers will use them or when. Farmers have been surveyed to project expected adoption levels once bST becomes available. Results indicate relatively rapid adoption—50-percent adoption within the first year and at least 80-percent within 3 years.

However, these surveys may not be accurate indicators of prospective adoption. Many of the bST surveys were conducted prior to the availability of widespread information on bST. Most other dairy technologies, moreover, have not been adopted rapidly. Artificial insemination technology is used only by 70 percent of dairy farms despite being available for some 40 years. Dairy Herd Improvement technology, available for 50 years, is used by only 45 percent of farmers.

OTA's statistical analysis of historical rates of technology adoption by dairy farmers provides another basis for predicting bST adoption. The analysis found:

- A slower rate of adoption than suggested by producer surveys of farmers on probable bST use (17 percent or less the first year).
- Regional variations in rates of technology adoption in the dairy industry. Based on this, bST adoption after 5 years is forecast to be 40 percent in the Pacific region, where technology adoption is most rapid, and 25 percent in the Corn Belt. This and other traditional milk production regions tend to be slower to adopt new technologies.

National Impacts

The interactions of technology adoption, dairy policy, and consumer reaction and their effects on future milk supply prices and returns to dairy farmers were captured using LIVESIM, a regional and national computer simulation model.[3] The policy options analyzed included a fixed price support, a price-support trigger, and a quota program. In all policy scenarios, the government purchases at least 3 billion pounds of milk annually to satisfy food-program needs (i.e., school lunch programs).

Fixed Price Support

This scenario fixes price at the 1989 level of $10.60 per cwt. This serves as a useful bench mark for comparing other policy options. In this case, the government purchases excess milk, at the support price, in order to clear the market. Without bST, milk production would increase from the present level of 144 billion pounds to 152 billion in 1995. With bST, production would increase an additional 4 to 5 billion pounds over the period (see table 1-1); government purchases would rise as high as 7 and 9 billion pounds in any one year, and overall would increase by 3 to 6 billion pounds over the minimum purchases of 3 billion pounds for food programs (see table 1-2).

Trigger Price Policy

This option triggers a price-support reduction each time the level of government purchases rises above 5 billion pounds annually. This scenario is similar to the producer-assessment option in the 1990 farm bill because the assessment will effectively trigger reductions in producer returns through milk price declines. Without bST, a single price-support reduction is triggered to a level of $10.10 per cwt in 1991. With bST, two price-support reductions are triggered in 1991 and another in 1993 to a level of $9.60 per cwt. These price reductions moderate production increases to keep government purchases near the 3-billion-pound minimum.

Quota Policy

A quota policy is another method to manage excess production. It establishes a level of milk production for each farm and provides effective disincentives to the farmer if production exceeds the quota. This might be accomplished by a two-tiered pricing system or some other mechanism that provides disincentives for producing over quota levels.

In the analysis, the quota policy was designed to maintain government purchases at or near the minimum government use target of 3 billion pounds. The quota was adjusted downward any year government expenditures exceeded 3 billion pounds. The results show that the quota avoids the high level of government purchases that result under the fixed price-support scenario (see table 1-2).

Demand Reduction

While claims that consuming milk and milk products from cows supplemented with bST or other new technologies could adversely affect human health have not been substantiated, a range of food safety and other considerations will affect consumer purchases. Policy needs to be designed considering the full range of potential consumer response; accordingly two scenarios of reduced milk consumption were analyzed.

Small Demand Reduction—In this scenario, per-capita demand decreases by 10 percent in 1991, 5 percent in 1992 (i.e., demand increases from 1991 to 1992), and 2.5 percent annually thereafter. Government purchases total 21.2 billion pounds in the first year (1991), 9.7 billion in 1992, and 8.4 billion in 1993. The support trigger decreases the price-support level to 9.10 per cwt in 1994. Even though government purchases are high for 3 years, the trigger mechanism seems to accommodate a temporary demand reduction.

Large Demand Reduction—The second demand scenario assumes a permanent 10-percent annual

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[3] A major focus of the analysis is on the use of bST because of its effect on productivity and commercial availability in the early 1990s.

Table 1-1—Level of Milk Production, With and Without bST, Under Alternative Policy Scenarios, 1990-98
(billions of pounds)

	Fixed support		Trigger		Quota	
Year	With bST[a]	Without bST	With bST[a]	Without bST	With bST[a]	Without bST
1990	144	144	144	144	144	144
1991	146	144	146	144	146	144
1992	146	143	146	143	145	144
1993	153	150	153	150	148	146
1994	153	149	152	148	150	148
1995	156	152	156	152	152	150
1996	157	153	155	153	155	153
1997	160	155	159	155	157	155
1998	161	157	159	157	160	157

[a] bST is assumed to be commercially available in 1991.

SOURCE: Office of Technology Assessment, 1991.

Table 1-2—Level of Government Purchases, With and Without bST, Under Alternative Policy Scenarios, 1990-98, Milk Equivalent (billions of pounds)

	Fixed support		Trigger		Quota	
	With bST[a]	Without bST	With bST[a]	Without bST	With bST[a]	Without bST
1990	3.0	3.0	3.0	3.0	3.0	3.0
1991	7.3	5.3	7.3	5.3	7.3	5.3
1992	4.3	3.0	3.0	3.0	3.5	3.0
1993	9.0	5.7	6.8	3.8	3.4	3.0
1994	6.0	3.0	3.0	3.0	3.1	3.0
1995	7.0	3.0	3.0	3.0	3.0	3.0
1996	4.8	3.0	3.0	3.0	3.0	3.0
1997	5.3	3.0	3.0	3.0	3.0	3.0
1998	3.6	3.0	3.0	3.0	3.0	3.0

[a] bST is assumed to be commercially available in 1991.

SOURCE: Office of Technology Assessment, 1991.

reduction in per-capita consumption. The trigger mechanism does not easily adjust the industry under this scenario. The support price must be lowered to $7.60 in 1997 to bring government purchases below 4 billion pounds (see figure 1-1). Such a low support price would make it difficult (impossible) for even the best managed dairy farms to avoid economic losses. A quota program or termination program (a one-time government buy-out of dairy herds) would be needed to bring government purchases back to the 3-billion-pound minimum. However, as this study shows, termination programs do not result in permanent reductions in supply. Quota programs can effectively reduce supply over a period of time. But with either program, approximately 1 million cows would need to be slaughtered causing beef prices to decline by 4 to 6 percent.

Conclusions

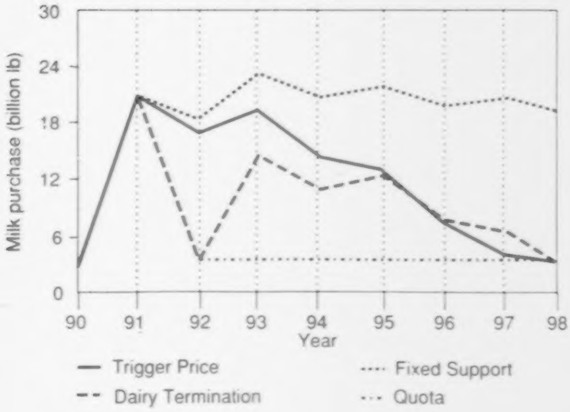
A mechanism such as the trigger price policy or producer assessments, which allow producer returns to decline as government purchases increase, could effectively adjust supply without excessively large inventory accumulations. However, if sharp reductions in demand accompany the introduction of bST, production quotas may be required. A quota policy, however, has some potentially harmful effects, including:

- higher production costs,
- elimination of dynamic adjustment within the industry,
- negative impact on beef cattle prices,
- difficulty of discontinuing, once initiated, and
- the capitalization of benefits into the quota.

Farm Level Impacts

The effects of emerging technology, dairy policies, and consumer demand can be more easily visualized by analyzing the impacts on representative dairy farms. The farm-level impacts of the three policy scenarios—fixed price support, trigger, and quota—over a 10-year period were analyzed using FLIPSIM, a farm level simulation model.

Figure 1-1—Projected Impact of a 10-Percent Permanent Demand Reduction on U.S. Government Milk Purchases Under Alternative Dairy Policies, 1990-98



SOURCE: Office of Technology Assessment, 1991.

Adoption Incentives

Once bST becomes available, strong incentives will exist to adopt the technology. Payoffs from bST adoption are substantial, regardless of region (see table 1-3). Nonadopters of bST will have more problems surviving and will be more likely to exit the industry. Likewise, dairy farmers located in States that have a moratorium on adoption will be placed at a substantial disadvantage relative to those in States where a moratorium does not exist.

Regional Competitiveness

Several reasons for regional shifts in milk production patterns can be seen in tables 1-3 and 1-4. Upper Midwest farms have problems realizing sufficient earnings to achieve a reasonable return on equity, compete, and survive. While Northeast farms perform better, they too were found to be at a disadvantage relative to Pacific and Southeast farms. In all regions, adoption of bST increases the potential to survive, especially for larger farms.

Policy Impacts

The fixed price-support policy, with its higher earnings, increases the probability of farm survival and the chances of earning a 5-percent return on initial equity (see table 1-5). While Upper Midwest dairies are able to maintain cash flow, net worth continues to erode on the 125-cow Upper Midwest dairy due to the relatively high investments in fixed assets (buildings, equipment, etc.).

From the producer standpoint, the quota program does not perform as well as the trigger price or fixed price-support programs. This is because the quota price objective is the same as the fixed price support ($10.60) and because restrictions on output curb expansion and raise production costs. To maintain dairy farm income under a quota system, the price objective must be sufficiently high to offset the effects of lower production—and this will result in higher prices to consumers.

The economic payoff from bST adoption is about the same for a trigger price policy and a fixed price-support policy. However, all the representative farms experienced at least a 20- to 40-percent decrease in economic payoff under a quota compared to the trigger price policy. Adoption of bST would be slowed by imposing a quota as opposed to the trigger price policy.

Even with reduced demand, strong incentives would exist for all farms in all regions to adopt bST. With the continuation of the current trigger policy, a 52-cow Upper Midwest dairy's probability of survival declines under a small decrease in demand, but is relatively enhanced by adopting bST (see table 1-6). The same is true for the larger dairies. If a major decrease in demand occurs, small and large dairy farms in the Upper Midwest will be most vulnerable.

Increased Pressure on Traditional Farms

A major controversy concerning bST is that it will force many dairy farms out of the industry, especially in traditional milk-producing regions. BST alone, however, will not force these traditional farms out of existence. As discussed earlier, the trend toward fewer total cows and larger farms has been underway for many decades. This trend is a result of the combination of emerging technology, industry economics, and policy. The trend will no doubt accelerate in the 1990s as the result of the combination of bST and other cost-reducing technologies and a more market-oriented dairy policy. As has been the case for years, such changes inherently puts increased pressure on traditional dairy farms. These pressures are not new, although they are accentuated by technological change.

If policymakers decide to change or at least slow this trend toward fewer but larger farms, changes in policy will be needed. First, to reduce the magnitude

Table 1-3—Impacts of bST Adoption on the Economic Viability of Moderate-Size Representative Farms, Assuming No Change in Demand for Milk Due to bST, Trigger Price Policy, by Region, 1989-98 (in percent)

	52-cow Upper Midwest		52-cow Northeast		350-cow Southwest		200-cow Southeast	
Measure of impact	Non-adopter	bST adopter	Non-adopter	bST adopter	Non-adopter	bST adopter	Non-adopter	bST adopter
Probability of survival[a]	58%	74%	100%	100%	95%	97%	100%	100%
Probability of earning 5-percent return on equity	58	74	100	100	95	97	100	100
Probability of increasing equity[b]	0	0	3	3	60	79	13	24
Present value of ending net worth as percent of beginning net worth[c]	16	29	72	77	109	128	76	89

[a] Chance that the individual farm will remain solvent through 1998, i.e., maintain more than a 10-percent equity in the farm.

[b] Chance that the individual farm will increase its net worth in real 1989 dollars through 1998.

[c] Present value of ending net worth divided by initial net worth indicates whether the farm increased (decreased) net worth in real dollars.

SOURCE: Office of Technology Assessment, 1991.

Table 1-4—Impacts of bST Adoption on the Economic Viability of Large Representative Farms, Assuming No Change in Demand for Milk Due to bST, Trigger Price Policy, by Region, 1989-98 (in percent)

	125-cow Upper Midwest		200-cow Northeast		1,500-cow Pacific		1,500-cow Southeast	
Measure of impact	Non-adopter	bST adopter	Non-adopter	bST adopter	Non-adopter	bST adopter	Non-adopter	bST adopter
Probability of survival[a]	95%	99%	100%	100%	100%	100%	100%	100%
Probability of earning 5-percent return on equity	90	95	99	100	100	100	100	100
Probability of increasing equity[b]	8	12	43	53	100	100	88	99
Present value of ending net worth as percent of beginning net worth[c]	57	69	92	102	195	214	129	147

[a] Chance that the individual farm will remain solvent through 1998, i.e., maintain more than a 10-percent equity in the farm.

[b] Chance that the individual farm will increase its net worth in real 1989 dollars through 1998.

[c] Present value of ending net worth divided by initial net worth indicates whether the farm increased (decreased) net worth in real dollars.

SOURCE: Office of Technology Assessment, 1991.

Table 1-5—Impacts of bST Adoption on the Economic Viability of Representative Large (125-cow) Upper Midwest Farms Under Alternative Dairy Policies, Assuming No Change in Demand for Milk, 1989-98 (in percent)

	Trigger price		Fixed price support		Quota	
Measure of impact	Non-adopter	bST adopter	Non-adopter	bST adopter	Non-adopter	bST adopter
Probability of survival[a]	95%	99%	99%	100%	85%	92%
Probability of earning 5-percent return on equity	90	95	95	98	67	78
Probability of increasing equity[b]	8	12	11	18	2	3
Present value of ending net worth as percent of beginning net worth[c]	57	69	67	78	37	46

[a] Chance that the individual farm will remain solvent through 1998, i.e., maintain more than a 10-percent equity in the farm.
[b] Chance that the individual farm will increase its net worth in real 1989 dollars through 1998.
[c] Present value of ending net worth divided by initial net worth indicates whether the farm increased (decreased) net worth in real dollars.

SOURCE: Office of Technology Assessment, 1991.

of adjustment the rate of technology adoption by traditional farms would need to be increased. This would require additional expenditures on public research and extension with the specific goal of enhancing the survivability of these farms. During times of rapid technological change, research and technology adoption strategies for traditional farms need to be developed and implemented by USDA, land-grant universities, and dairy cooperatives if these farms are to survive.

Second, dairy policy may need to change back to a fixed price-support policy. As seen in the previous analysis, a fixed support policy enhances the traditional farm's probability of survival compared to other policies. It is, however, significantly more costly to the government than current policy.

It is possible to at least slow the trend toward fewer total cows and larger dairy farms. However, such change may be costly. As noted, to keep less progressive traditional farms in the industry will require increased expenditures for research and extension to improve technology adoption and increased funds to support the price of milk at a level that will allow these farms to compete. Policymakers will need to weigh the benefits of traditional farms with these costs in determining the policy path to follow in the 1990s. This is particularly the case for dairy farms outside the areas with a comparative advantage in dairying where a large share of feed supplies are purchased.

Science Policy and Emerging Technology

The controversy surrounding biotechnology—including bST—raises questions concerning what social needs are being met by these technologies and the appropriateness of public sector investment in their development. The questions raised point to the need for broadbased, ex ante information concerning new technologies. Presently, little information about new technologies is available prior to commercialization. There is no institution within the agricultural science policy community that develops information on the benefits and risks of any technology ex ante. There also is no formal structure that provides input to decisionmakers from all affected parties (farmers, marketers, researchers, consumers, etc.). Thus there is no comprehensive information about the benefits and risks of a new technology prior to commercialization and, therefore, no inclusive criteria to determine how public research resources should be allocated.

The development of an institutional framework to provide and act on such information is needed. Had such an institution been in existence a decade ago, it is possible that the bST controversy could have been avoided or minimized. Consideration of the costs and benefits of new technologies and input from a wider range of clientele could lead decisionmakers to consciously choose a different allocation of public sector research funding than that which occurs in the absence of such information.

Clearly, all benefits and risks of new technology development cannot be determined a priori, and overcentralization of research decisionmaking raises legitimate concerns. Care must be taken in establishing such an institution. However, a broad based discussion of issues involving all relevant users of new technologies can point to potential problems, determine further research needs, and provide information about the relative social benefits to be gained

Table 1-6—Impacts of bST Adoption on the Economic Viability of Moderate-Size Representative Farms, Assuming Small Decrease in Demand for Milk Due to bST, Trigger Price Policy, by Region, 1989-98 (in percent)

	52-cow Upper Midwest		52-cow Northeast		350-cow Southwest		200-cow Southeast	
Measure of impact	Non-adopter	bST adopter	Non-adopter	bST adopter	Non-adopter	bST adopter	Non-adopter	bST adopter
Probability of survival[a]	40%	48%	100%	100%	88%	94%	99%	100%
Probability of earning 5-percent return on equity	40	48	100	99	88	94	89	94
Probability of increasing equity[b]	0	0	1	2	35	51	4	9
Present value of ending net worth as percent of beginning net worth[c]	3	10	65	70	79	99	58	71

[a] Chance that the individual farm will remain solvent through 1998, i.e., maintain more than a 10-percent equity in the farm.

[b] Chance that the individual farm will increase its net worth in real 1989 dollars through 1998.

[c] Present value of ending net worth divided by initial net worth indicates whether the farm increased (decreased) net worth in real dollars.

SOURCE: Office of Technology Assessment, 1991.

by investments in competing technologies. The seeds of such a framework can be found in the first report of this series, *Agricultural Research and Technology Transfer Policies for the 1990s*. Congress has subsequently taken the first step by authorizing an Agricultural Science and Technology Review Board in the 1990 farm bill that will begin to develop ex ante information on selected technologies. It is a beginning, but much more work will be needed in the future.

CONCLUSIONS

Emerging technologies, such as bST, industry economics, and public policy will play critical roles in shaping the U.S. dairy industry in the decade of the 90s. Advances in health, reproduction, and information technology all will affect the industry. The most dramatic impact will be due to bST. Claims have been made that bST is unsafe in consumer food products, an unsafe technology for cows, and a technology that will economically destroy many traditional farms. This report concludes just the opposite. It is a technology that, based on today's research findings, poses no additional risk to consumers, one that does not produce adverse health effects to cows, and one that alone will not economically disadvantage the traditional farm operator. Emerging technologies (including bST), industry economics, and current dairy policy will merely accelerate an existing trend—the pressure on traditional farms to grow or exit the industry. Changes in: rate of technology adoption, research and extension policy, and perhaps dairy policy may be required to reverse this trend.

A national dairy policy that provides a mechanism for allowing producer returns to decline as government purchases increase, such as the trigger price-support policy or producer assessments as provided for in the 1990 farm bill, could effectively adjust supply without excessively large inventory accumulations. However, if demand for dairy products declines sharply with the introduction of bST, supply-management programs such as production quotas or termination programs may be required. Termination programs are costly and do not effectively reduce supply over a period of time. Production quotas can effectively control supply. However, they also freeze regional production shifts and (because the quota has an economic value) make it more costly for new entrants into the industry. Because of costs and rigidities associated with quota programs, consideration might be given to observing government purchases over a 2-year, as opposed to a 1-year, period before implementing such a program. This would permit a more accurate assessment of whether the demand reduction is temporary or permanent.

The introduction of bST has caused considerable controversy. Little, if any, information was available early in its development to foresee the biological, economic, social, and political impacts of its potential adoption. Lack of such information establishes a clear need to consider the benefits and risks of new technology more seriously and to use that information in allocation of public sector research funds. An institutional framework needs to be developed to provide this information and involve all the relevant users of new technology.

Chapter 2

Overview of the Dairy Industry

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Chapter 2

Overview of the Dairy Industry

The dairy industry is large, dynamic, and driven by a number of forces. Dairy products account for about 13 percent of total cash receipts from all farm commodities. In 1989, cash receipts from dairy products totaled $19.3 billion; only cattle and calves brought greater returns. Although milk is produced and processed in every State, two-thirds of the total 1989 milk supply was produced in 10 States (1). At least half of the total 1989 U.S. milk production came from Wisconsin, California, New York, Minnesota, and Pennsylvania.

A central feature of the dairy industry is the relatively constant 1.5 to 2.0 percent annual increase in output per cow (see figure 2-1). Exceptions have occurred only after major weather disruptions (leading to sharp increases in feed prices in the early 1970s and in 1989) and with changes in government policy (namely, the 1983-84 milk diversion program). This chapter describes the supply, demand, and regulatory forces driving the industry and the resulting policy issues for the 1990s.

FORCES DRIVING THE INDUSTRY

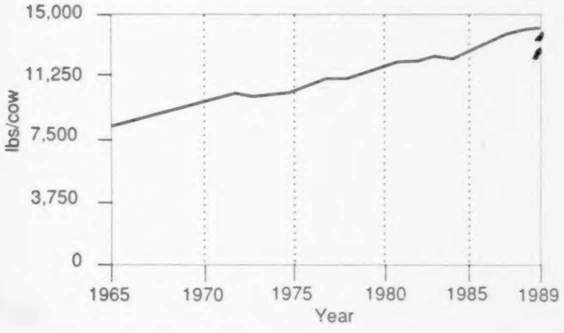
Technological Change

Increases in milk output per cow have not come automatically; they reflect the continuous adoption by farmers of artificial insemination, Dairy Herd Improvement Association (DHIA) recordkeeping, three-times-a-day milking, automated feeding, forage testing, and other technologies that periodically enter the market as products of public- and private-sector research and development. Productivity has also risen because of constant improvement in the quality of management, which in turn partially reflects improved packaging of technology to increase output per cow.

With milk consumption per capita growing less rapidly than output per cow, there has been a gradual national trend toward reduced cow numbers (see figure 2-2). This trend was interrupted in the early 1980s by government policy that supported the price of milk at 80 percent of parity in the face of declining feed prices.

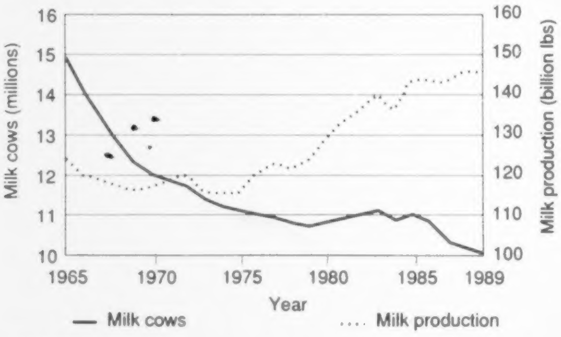
The U.S. Department of Agriculture (USDA), in reporting production statistics, divides the United States into 10 farm-production regions (see figure 2-3). Changes in output per cow have not been uniform nationally (see figure 2-4). For example, USDA's Pacific region had a milk output per cow of 18,389 pounds in 1988, whereas the U.S. average was 29 percent lower (14,213 pounds). The Pacific region's output per cow is 51 percent higher than that of the Appalachian region. While climatic conditions contribute to some of these differences, the main factors seem to be progressiveness, philosophy, and quality of management—factors that also are believed most directly to impact the adoption of

Figure 2-1—Annual Milk Output Per Cow, 1965-89



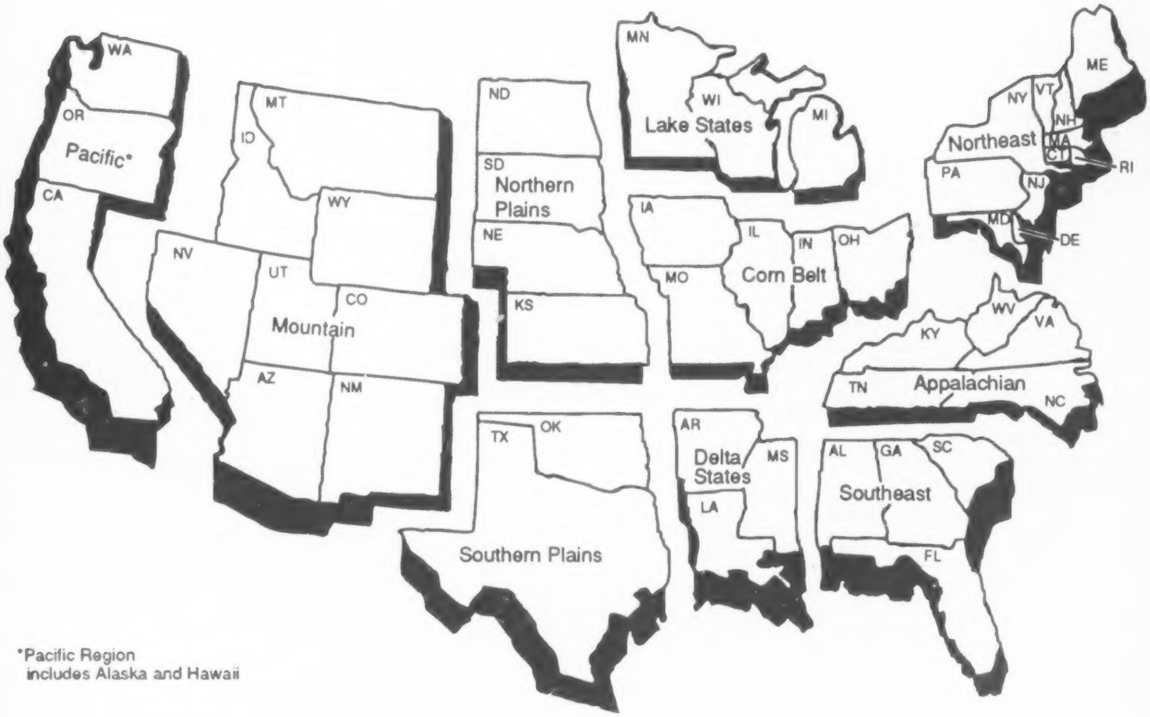
SOURCE: U.S. Department of Agriculture, Economic Research Service, *Dairy Situation and Outlook Report*, various years, 1965-1990.

Figure 2-2—Average Number of Milk Cows on Farms and Total Milk Production, 1980-89



SOURCE: U.S. Department of Agriculture, Economic Research Service, *Dairy Situation and Outlook Report*, various years, 1965-1990.

Figure 2-3—USDA Farm Production Regions



*Pacific Region includes Alaska and Hawaii

SOURCE: U.S. Department of Agriculture, Economic Research Service, 1990.

technologies. These factors in turn are related to the availability of extension education services, consultants, and the infrastructure of input and technology suppliers. Success in technology adoption will be one of the major factors determining future milk production patterns. Other major factors impacting these patterns include dairy policies, environmental policies, water availability, population pressures, climate, and resource availability.

Economies of Size

Larger dairy farms, as a general rule, experience lower per-unit production costs. Studies currently in progress suggest that in traditional milk production regions, such as the Upper Midwest and the Northeast, economies of size (reduced per-unit production costs associated with increased farm size) have led to the establishment of several larger size dairy operations. And current research suggests that these dairy operations have the potential to realize even larger economies of size.

Regional differences in dairy herd size are associated with different economies of size (see figure 2-5). The Pacific coast and Florida lead the Nation with herd sizes typically in the 500- to 1,500-cow range and enjoy the lowest production costs per unit output. In traditional milk production regions of the Upper Midwest and Northeast, dairies are typically in the 50- to 150-cow range, and production costs are relatively high.

Costs of Production

Substantial regional differences in costs of producing milk reflect regional differences in output per cow as well as in herd size[1] (see figure 2-6). The Economic Research Service/USDA has estimated the cash costs and total economic costs of production since 1974. Cash costs depend primarily on the share

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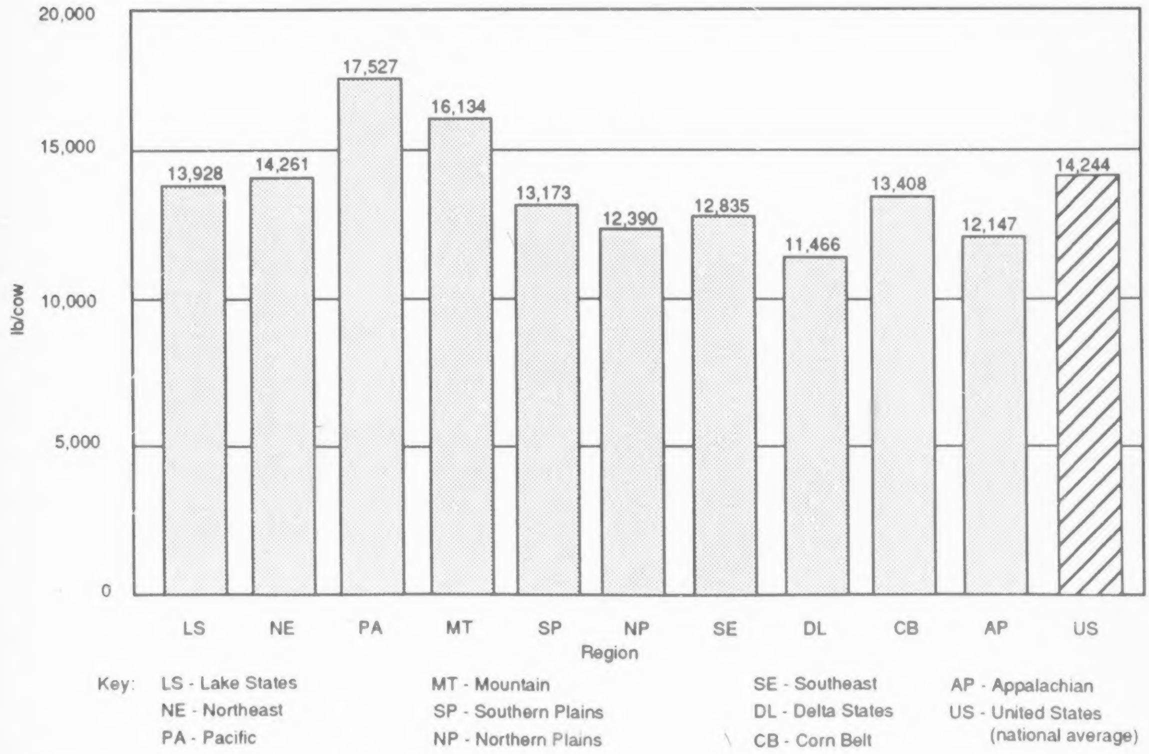
[1] The USDA cost of production regions do not include the same States as the production regions indicated in figure 2-3. With minor exceptions, the Upper Midwest cost of production region is equivalent to the Lake States production region.

Figure 2-4—Milk Output Per Cow by Region, 1989



SOURCE: U.S. Department of Agriculture, Economic Research Service, 1990.

of inputs purchased and milk output per cow.[2] For example, in the Southeast, where dairies purchase most of their feed inputs (about 50 percent of production costs) and where average output per cow is low (12,604 pounds, see figure 2-4), the cash cost averaged $11.63 per hundredweight (cwt) (see figure 2-6). Dairies in the Pacific region also purchase a high percentage of their inputs but have the highest output per cow (17,527 pounds), thus yielding a moderate cash cost of $9.07 per cwt. Regions that grow much of their feed have the lowest cash costs.

The level of cash costs is significant from a policy perspective. Farmers who are not covering cash costs have strong economic incentives to shut down their operations. They are either building debt or eroding equity on virtually a daily basis. Not surprisingly, farmers in high-cash-cost regions likely

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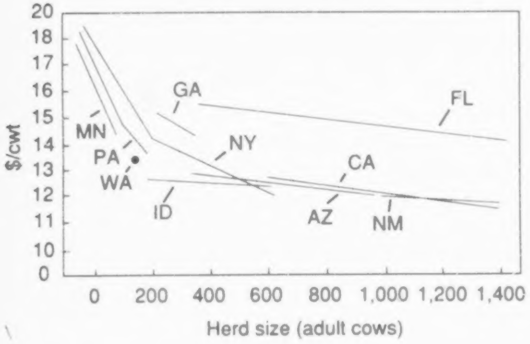
[2] Cash costs reflect the minimum break-even prices needed to produce in the short run. Subtracting cash costs from the gross value of production leaves net cash available before replacement of depreciable assets. It excludes income taxes and principal payments.

Figure 2-5—Milk Production Costs Related to Herd Size, for 10 States, 1985



SOURCE: Office of Technology Assessment, 1991.

are the first to complain about milk prices being too low.

Total economic costs include all fixed and cash costs of production.[3] Fixed costs are highest in regions that grow a large percentage of their feed, have substantial investments in housing and feed storage (silos), and/or are expanding rapidly (meaning high depreciation costs). Thus, while the Upper Midwest and Northeast regions have among the lowest cash costs, they have relatively high total economic costs due to their large housing and feed-storage investments.

Total economic costs are meaningful from a policy perspective because they influence the long-run economic viability of a region. If these as well as cash costs are not offset by high milk prices, farmers will have no incentive to invest. This is the case in the Upper Midwest and Corn Belt regions where the dairy industry is in relative economic stagnation and even decline.

Dairy Receipts

Dairies obtain most of their receipts from milk (about 90 percent) and from the sale of cows (no more than 10 percent). The price of milk is determined nationally and regionally by the interaction of government policy, consumer demand, and the supply of milk. Government dairy programs include the Federal and State milk marketing order programs and the Federal dairy price support program.

The milk marketing order programs regulate the price of milk eligible for fluid consumption: processors are required to pay minimum class prices based on how the milk is used. The lowest prices are for Class III uses (milk used to manufacture butter, cheese, and nonfat dry milk). Milk used for soft products (ice cream and yogurt) receives a slightly higher Class II minimum price, and milk used for fluid consumption receives a substantially higher Class I minimum price. Dairy producers receive the average (blend) of the three class prices weighted by the share of milk used in each class. Class II and III minimum prices are fixed at the average of the market prices paid by manufacturers in Wisconsin and Minnesota. Class I prices are determined by the Minnesota-Wisconsin prices plus a differential that increases with increasing distance from Eau Claire, WI. Thus, Federal milk marketing order Class I (fluid use) prices increase from the Upper Midwest to the South and East.

The Federal Government purchases cheese, butter, and nonfat dry milk in quantities sufficient to maintain market price at a minimum level, established by the Federal price support program. Reductions in the price of milk may occur for several reasons: because the government lowers the price support, because the share of milk used for fluid purposes in a marketing order declines (due to an increase in supply or a fall in demand), or because premiums over minimum order prices (based on supply and demand conditions) paid by processors decline.

This combination of government-administered and market-determined price relationships is important because it has a marked impact on the regional distribution of milk receipts (see figure 2-7). Receipts are highest in the Southeast (14.87 per cwt) and lowest on the Pacific coast (11.13 per cwt). The Upper Midwest has slightly higher milk receipts ($11.92 per cwt) than the Pacific region.

Net Income

Profits vary regionally with receipts and costs. The combination of high costs and low prices in the Upper Midwest in 1988 led to a negative cash income (-$0.11 per cwt) and an even lower return to management (-$0.62 per cwt) (see figure 2-8).[4] The

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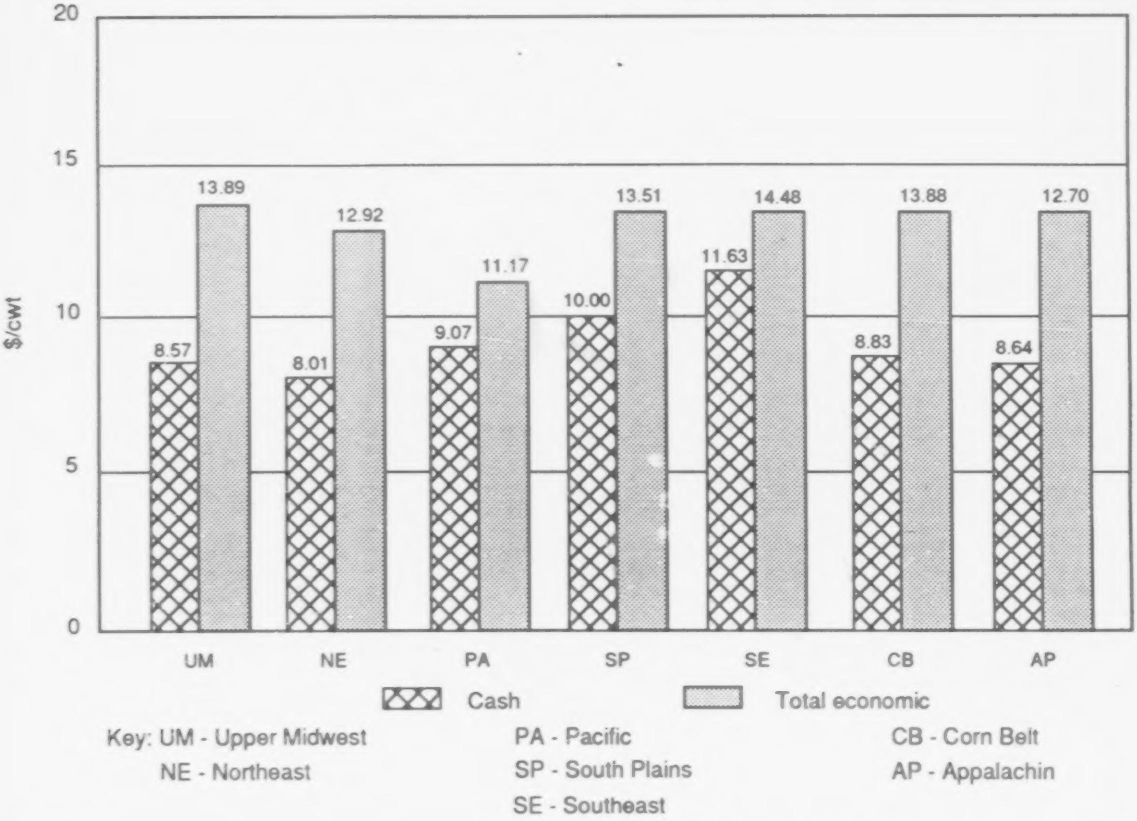
[3] Total economic costs do not include a return to management.

[4] Cash income is the difference between gross value of production and cash expenses and capital replacement.

Figure 2-6—Regional Differences in Costs of Producing Milk, 1988



SOURCE: U.S. Department of Agriculture, Economic Research Service, *Economic Indicators of the Farm Sector*, 1989.

Corn Belt also experienced a loss in returns to management (of $0.27 per cwt). The highest return regions were the Southeast and Appalachia. Despite high costs, the Southeast realized higher returns due to favorable treatment under the Federal milk marketing order system. The Pacific region realized a favorable return despite having the lowest receipts. This reflects the overall efficiency of relatively industrialized production on the west coast.

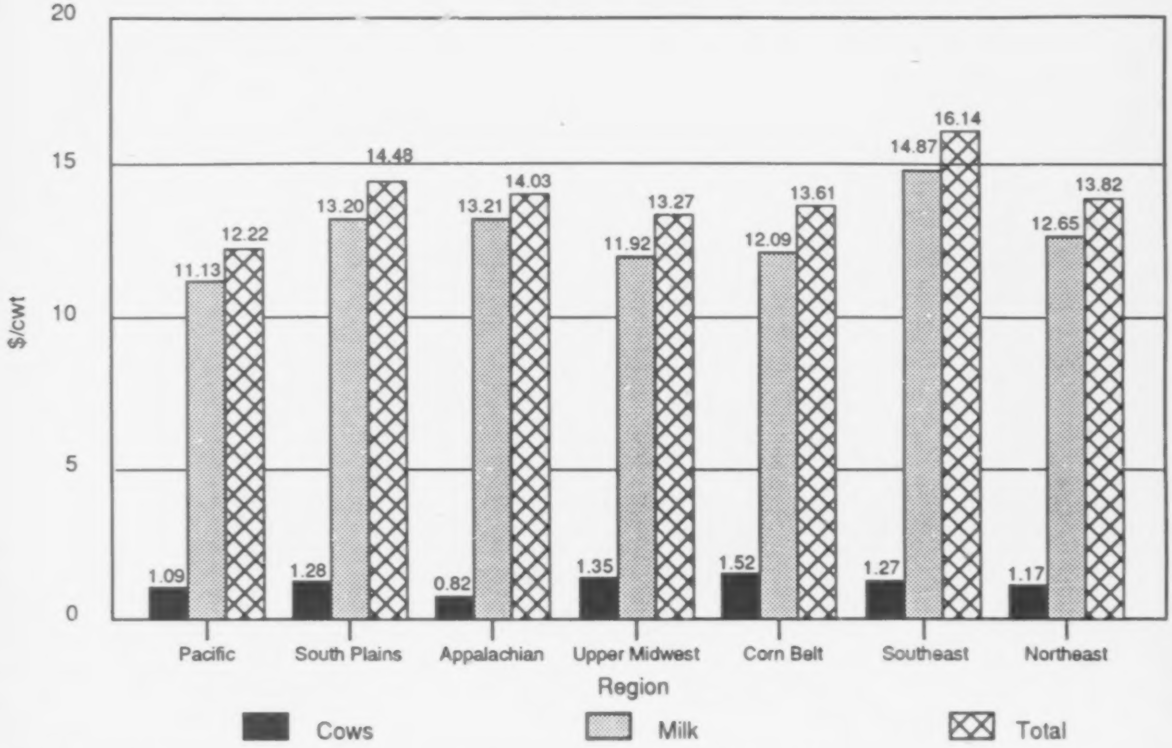
The income situation improved for dairy farms in the traditional milk producing regions in 1989 and 1990 when farm milk prices increased. These farms experienced positive returns in those years. However, in the early months of 1991 prices declined significantly and are expected to fall by 15 to 20 percent for the year compared to 1990. Dairy farms in the traditional milk producing regions are expected to lose equity under these conditions. Farms in the nontraditional areas, such as the Pacific region, are expected to operate much closer to their break-even point.

Regional Production Changes

Sustained regional differences in profit lead to shifts in the geography of production. The largest increases in milk production have been in the West and Southwest, where marketings have risen by nearly 40 percent since 1980 (see figure 2-9). Milk production in the traditional dairy areas of the Lake States and Northeast has increased by 6.5 and 4.0 percent, respectively. The Corn Belt, which consistently has had the lowest net returns, experienced a production increase of only 4.9 percent.

However, no region is homogeneous. During the 1980s, for example, centers of rapidly increasing production developed within regions (i.e., central Texas and southern Georgia). In the late 1980s, persistent production declines occurred in Minne-

Figure 2-7—Regional Differences in Receipts From Dairy Farm Sales, 1988



SOURCE: U.S. Department of Agriculture, Economic Research Service, *Dairy Situation and Outlook Report*, 1989.

sota—traditionally one of the largest dairy States. Because of the higher cost conditions associated with smaller dairies (see figure 2-5), and low profits (see figure 2-8), significant sections of the Lake States may have lost its comparative advantage to other regions. Questions arise as to whether traditional Federal order pricing institutions, which rely on Minnesota and Wisconsin as the base point for pricing milk (the M-W price), are appropriate in today's milk industry. The answers to these questions are complex and merit further study and debate (2, 3).

While the national share of milk production in the Lake States and the Northeast has declined by at least 2 percent since 1980, these two regions still produced almost half of the Nation's milk supply in 1989 (see figures 2-10 and 2-11). If these regions are to maintain their role as "dairy States," major changes in scale of operation, levels of technology adoption, support for dairy research and extension, and, perhaps, dairy policy may be required.

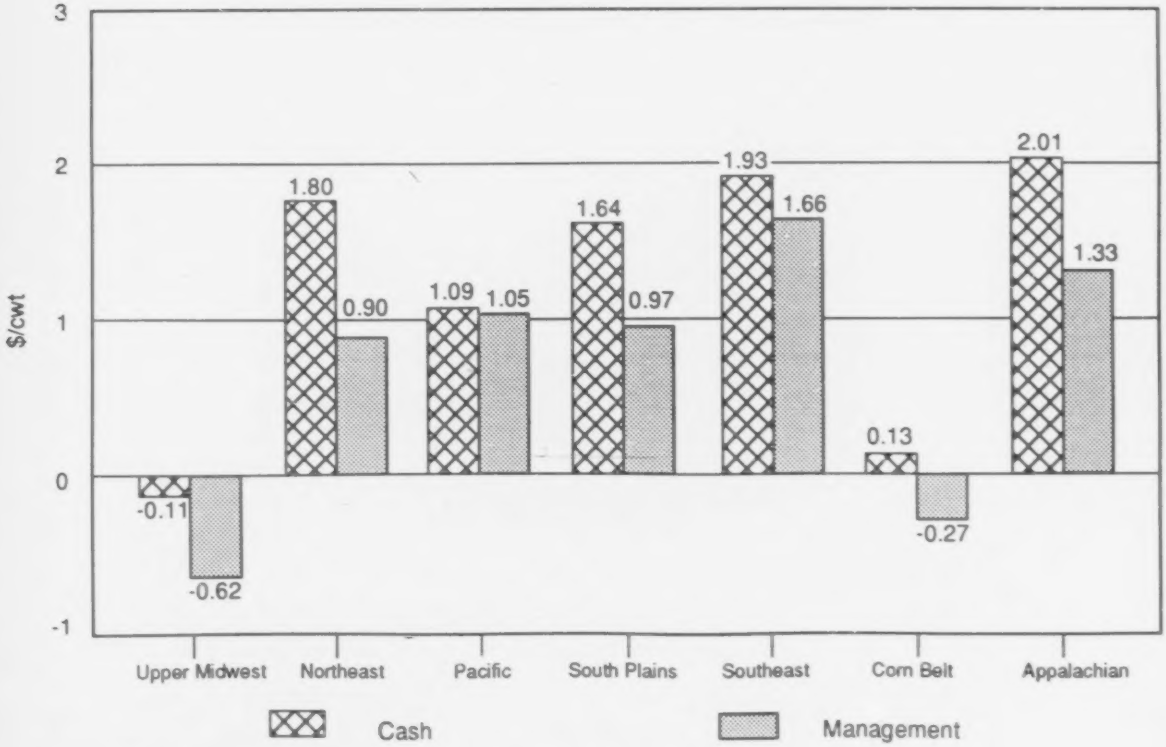
Demand Changes

Changes in demand may be as important as changes in supply in determining the future course of the dairy industry. Shifts in population toward the West and South have favored increased milk production in these regions.

There have also been major changes in demand for individual dairy products, such as sharply reduced butter consumption, increased lowfat (2.0 percent butterfat or less) milk consumption (see figures 2-12 and 2-13), and increased cheese consumption. The shifts from whole milk to lowfat milk and the rapidly rising cheese consumption have been particularly dramatic. The trend away from consuming whole milk likely reflects increasing consumer concerns about calories, fat, and cholesterol consumption.

Cheese is overwhelmingly the bright spot in terms of dairy product demand. While American-style cheeses (predominantly cheddar) have experienced substantial growth (see figure 2-14), the demand for

Figure 2-8—Regional Differences in Net Income (profit), 1988



SOURCE: U.S. Department of Agriculture, Economic Research Service, *Dairy Situation and Outlook Report*, 1989.

other cheeses (predominantly Italian-style) has grown even more rapidly and consistently (see figure 2-15). Italian-style cheese demand is largely a result of the rapidly growing convenience and fast food (pizza) market. Therefore, cheeses have capitalized on consumer trends toward microwave convenience and eating out. Other dairy products have not benefited as much from these changing market trends.

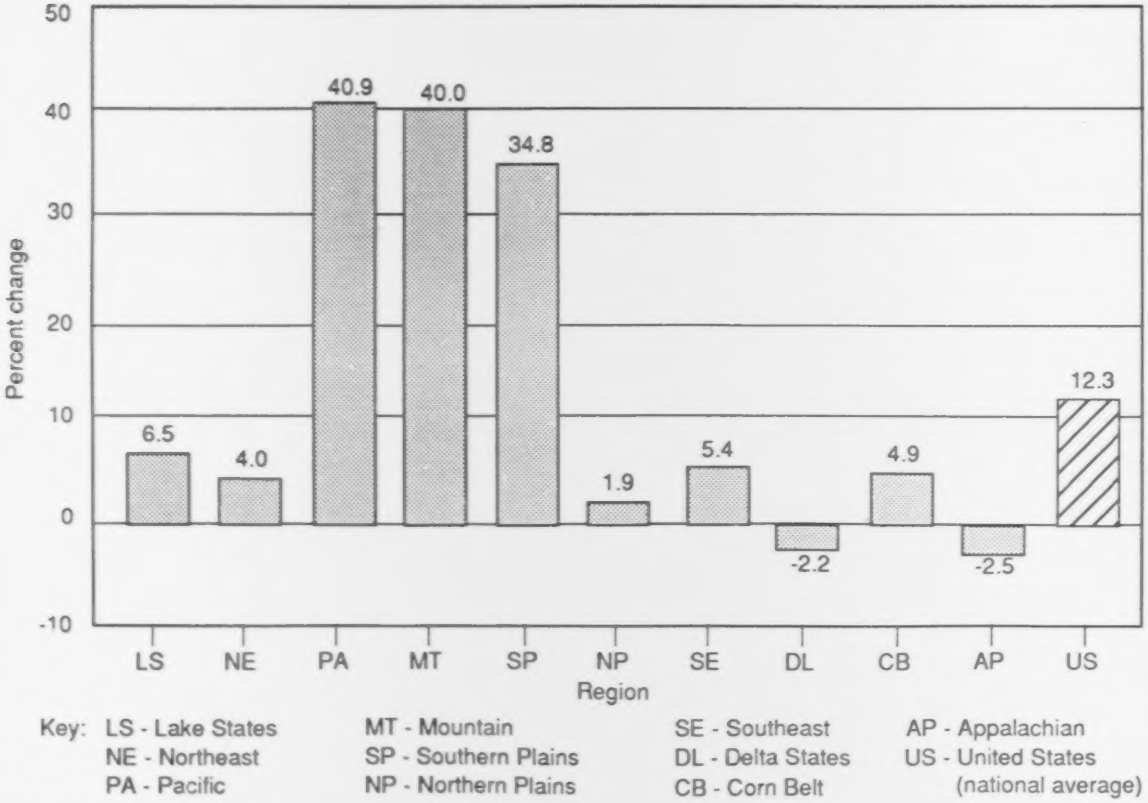
MAJOR DAIRY POLICY ISSUES

The milk industry may well be the most highly regulated of any in the United States. A complex system of health, food safety, and labeling regulations exist at the Federal, State, and local levels. These regulations reflect the perishability of the products, which are ideal media for the growth of microorganisms; the potential for their adulteration; the potential for drugs and/or chemical residues related to milk production processes; and the potential for variations in the nutritional value of products. Over time, more stringent water quality standards have been placed on dairies, affecting the management of animal wastes and runoff. In some instances, air pollution regulations have also been imposed. Overlying the EPA- and FDA-oriented regulations is an extensive set of Federal and State milk-pricing regulations. These include a network of Federal milk marketing orders, State milk marketing orders, and the milk price-support programs discussed earlier. The following section summarizes some of the major issues of dairy policy and how policy considerations and regulatory mechanisms may interact to shape the industry's future.

Butterfat Surplus

Nutrition- and diet-conscious consumers increasingly have shunned higher butterfat products. (Increased consumption of premium ice cream is one of the few exceptions to this trend.) As a result of declining demand, a butterfat surplus has developed, although overall, milk supply and demand have been in relative balance during the late 1980s and early

Figure 2-9—Change in Milk Production by Region, 1980-89



SOURCE: U.S. Department of Agriculture, Economic Research Service, 1990.

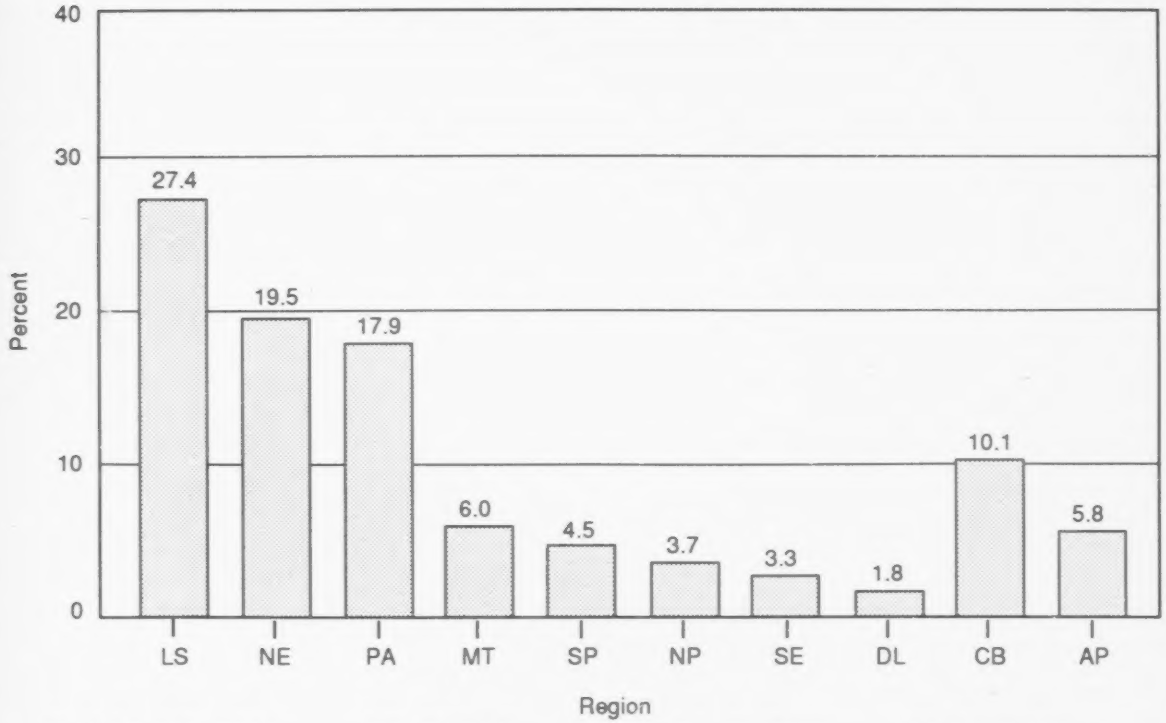
1990. Commodity Credit Corporation (CCC) price-support purchases of butterfat have continued even as USDA has had to enter the commercial market to satisfy cheese demand for its child nutrition programs. USDA has attempted to remedy the butterfat surplus problem by consistently lowering the price of butterfat to stimulate consumer demand while holding the cheese price constant. This strategy has been only partially successful. Surpluses in cheese and nonfat dry milk (NFDM) have completely disappeared since 1988 and butterfat surpluses continue (see figure 2-16).

Future trends could further complicate the butterfat surplus problem. Lowfat cheeses and lowfat ice cream are capturing a larger part of that market. Fat substitutes are also being developed for use in ice cream, and perhaps other dairy products. These trends represent a two-edged sword; they could result in increased total demand for dairy products, yet further reduce butterfat demand.

Research progress in removing cholesterol from butterfat may be the solution to the problem. However, for reasons of diet and health, consumers are concerned over a range of issues: total fat consumption, calorie intake, saturated fat consumption, and cholesterol intake. Fat substitutes aggravate the butterfat problem whether or not cholesterol is effectively removed from butterfat.

From the above analysis, it seems that the solution to the butterfat problem may be to reduce butterfat production. This can be partially accomplished by changing feeding practices in the short run and by breeding for reduced butterfat in the long run. Pricing incentives must exist for either of these potential solutions to occur. Milk currently is priced, to a large extent, on the basis of butterfat content.

Figure 2-10—Share of Milk Production by Region, 1989



Key: LS - Lake States
NE - Northeast
PA - Pacific
MT - Mountain
SP - Southern Plains
NP - Northern Plains
SE - Southeast
DL - Delta States
CB - Corn Belt
AP - Appalachian
US - United States (national average)

SOURCE: U.S. Department of Agriculture, Economic Research Service, 1990.

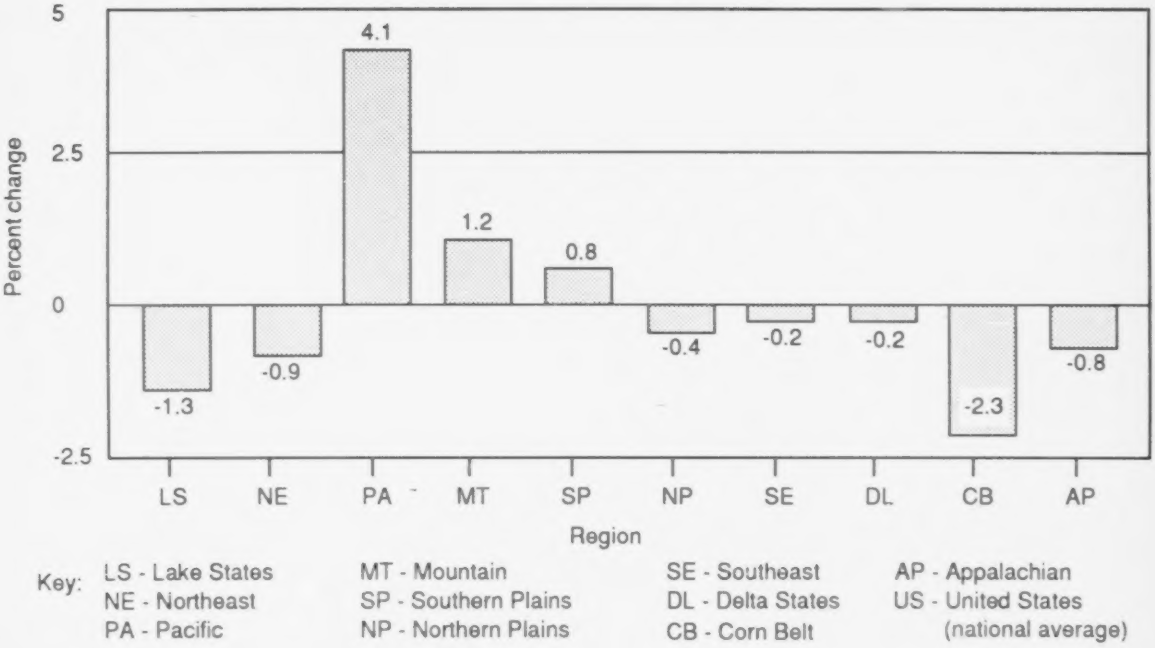
Shifts to pricing on the basis of protein or nonfat solids are possible and practiced in some markets. Industry initiatives and USDA leadership are required to obtain widespread adoption of such innovative pricing alternatives.

Milk Price Support

Related to the butterfat issue is the mechanism for adjusting the milk price-support level. From 1949 through 1981, the milk price-support level was set as a percent of parity (a price that will give a farmer the same purchasing power he/she had in a base period). Generally, the Secretary of Agriculture was given a discretionary range of 75 to 90 percent of parity within which to set the milk price-support level. In 1981, a trigger mechanism relating changes in the price support to the level of government purchases was adopted. Under the 1985 farm bill, the milk price support was raised in $0.50 per cwt increments when CCC purchases of dairy products were projected for the following year to be less than 2.5 billion pounds and decreased at the same rate when such purchases were projected to be greater than 5.0 billion pounds. The pounds were measured on a butterfat-milk-equivalent basis. The butterfat basis became an issue when CCC cheese and dry milk purchases ended in 1989, and as butterfat purchases increased.

The 1990 farm bill dairy policy provisions froze the price support at $10.10 per cwt through 1995. For deficit reduction purposes, it assesses $0.05 per cwt for all milk produced in 1991 and $0.1125 in 1992-1995. This assessment is refunded on proof that the farmer's milk production was not increased over the previous year. The Secretary is required to prepare a report with recommendations to Congress on how it plans to limit growth of CCC purchases of dairy products by August 31, 1991 with exclusions

Figure 2-11—Change in Share of Milk Production by Region, 1980-89



SOURCE: U.S. Department of Agriculture, Economic Research Service, 1990.

of cow slaughter and price-support reduction options. If Congress fails to enact dairy legislation by 1992 and CCC purchases are expected to exceed 7 billion pounds, an assessment covering the full cost of the CCC purchases over 7 billion pounds is authorized.

As a result of these decisions, the following policy issues are pending as the industry enters the 1990s:

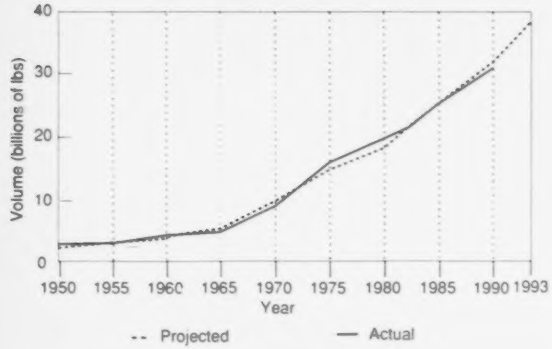
- the potential for effective demand expansion programs—the 1990 farm bill authorizes a processor-funded demand expansion check-off if approved by referendum,
- the potential for developing effective temporary supply and/or management systems that do not lead to industry inefficiencies and rigidity in production patterns,
- what to do about declining demand for butter and the accumulation of butter stocks, and
- how much discretion the Secretary of Agriculture should have in determining the provisions of dairy policy.

Price Instability

As the price-support level has declined, the price of milk and manufactured dairy products has become more variable. This instability is the result of the interaction of an inelastic supply and demand for milk. With lower price supports, instability is particularly evident in autumn when milk supplies are often relatively short. For example, in 1989, the Minnesota-Wisconsin (M-W) price rose from a low of $11.20 per cwt in May to $15.10 in December. It then fell back to $12.20 in March 1990 (see figure 2-17). By September 1990, the M-W was approaching the milk price-support level of $10.10 per cwt.

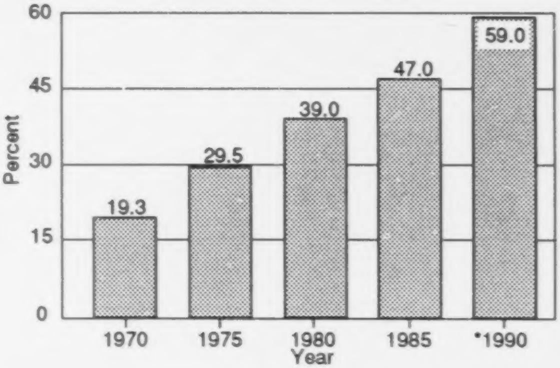
From an industry perspective, one of the benefits of dairy policy has been the stability provided by the price support and Federal order program. Current predictions regarding M-W prices are widely variable. While some argue that the milk price support will once again determine the price of milk under the 1990 farm bill, others suggest that significant segments of the milk industry cannot survive such low prices. Planning for the future has become exceedingly difficult for producers, processors, USDA, and Congress.

Figure 2-12—Actual and Projected Consumption of Lowfat Milk, 1950-93



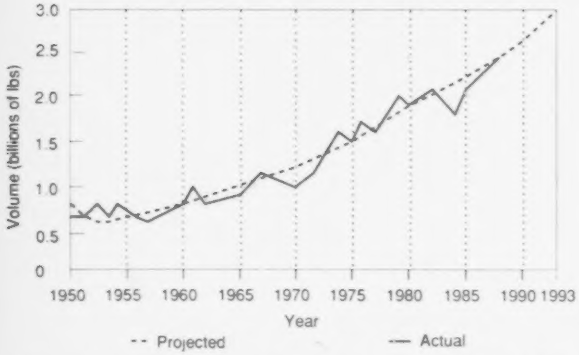
SOURCE: Reginald Adamus and Emerson Babb, "Projections of U.S. Dairy Product Consumption, 1989-1993," Food and Resource Economics Department, University of Florida, 1990.

Figure 2-13—Market Share of Lowfat Milk as a Percent of Total Fluid Milk Consumption



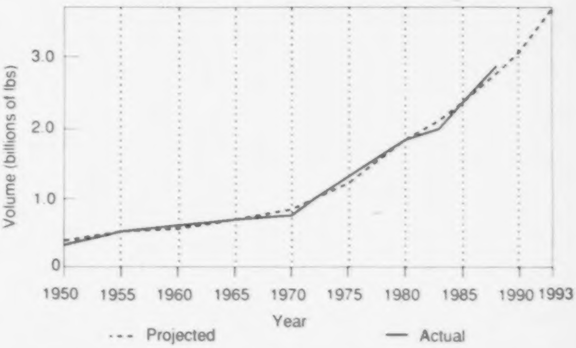
SOURCE: U.S. Department of Agriculture, Economic Research Service, *Dairy Situation and Outlook Report*, various years, 1970-1991.

Figure 2-14—Actual and Projected Consumption of American Cheese, 1950-93



SOURCE: Reginald Adamus and Emerson Babb, "Projections of U.S. Dairy Product Consumption, 1989-1993," Food and Resource Economics Department, University of Florida, 1990.

Figure 2-15—Actual and Projected Consumption of Other Cheese



SOURCE: Reginald Adamus and Emerson Babb, "Projections of U.S. Dairy Product Consumption, 1989-1993," Food and Resource Economics Department, University of Florida, 1990.

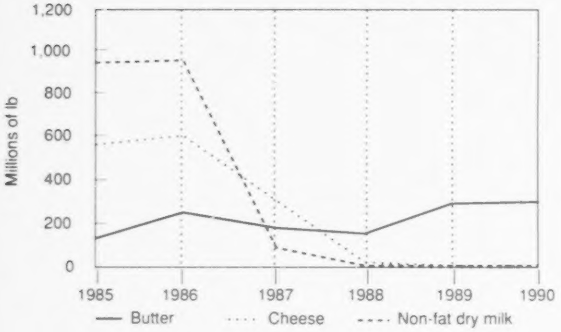
Milk Production Controls

During the 1980s, a dairy diversion program and a dairy termination (buyout) program were implemented as means of reducing milk production—in addition, the price-support level was lowered from a high of $13.10 per cwt to $10.10 per cwt. The termination program was considerably more effective than the diversion program but also more controversial because of its negative impact on the price of beef.

The combination of the termination program and lower price supports has brought milk production into relative balance with consumption. With this accomplished, attention has turned to the potential need for production controls should surpluses once again accumulate. This could happen if milk supply increases sharply due to rapid adoption of a new technology, and/or if demand falls due to negative consumer reaction to the same technology. After passage of the 1990 farm bill, options for production controls (or inventory management) would appear to include:

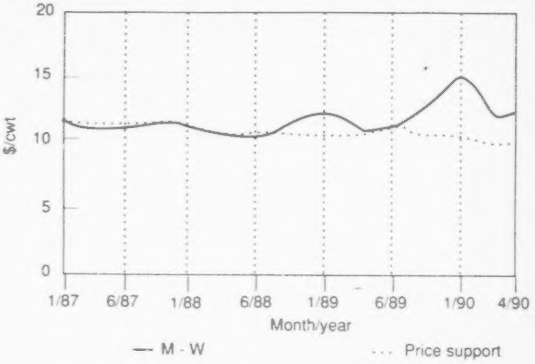
- utilization of a combination assessment and production control system;
- implementation of some type of quota system; and
- in concert with either assessments and/or quotas, an aggressive program to expand domestic and foreign demand.

Figure 2-16—Uncommitted Government Dairy Product Inventories, 1985-90



SOURCE: U.S. Department of Agriculture, Economic Research Service, *Dairy Situation and Outlook Report*, various issues, 1985-1991.

Figure 2-17—Minnesota-Wisconsin (M-W) Price and Milk Price-Support Level, January 1987 to April 1990



SOURCE: U.S. Department of Agriculture, Economic Research Service, *Dairy Situation and Outlook Report*, various issues, 1988-1991.

Federal Milk Marketing Orders[5]

Historically, decisions regarding Federal milk marketing orders have been left largely to the Secretary of Agriculture. However, the 1985 farm bill increased Class I milk prices, emphasizing markets distant from the Upper Midwest. In 1988, the General Accounting Office (GAO) published a study indicating that Federal orders tended to favor regions to the South and East at the expense of producers in the Upper Midwest. The GAO report recommended a gradual but progressive succession of steps to reduce the level of regulation in Federal orders.

In light of these developments, the Secretary of Agriculture has initiated a series of national hearings, which were to be completed by the end of 1990. The 1990 farm bill mandates decisions on Federal orders by 1992. Major issues identified for the hearings include:

- the level of class prices for milk,
- the number of classes and products included,
- the geographic structure of prices including the potential for multiple basing points,
- the need for uniformity in order provisions, and
- the appropriate basis for new Federal order class prices (as opposed to the Minnesota-Wisconsin series).

Basic Formula Price

Since the 1960s, the Minnesota-Wisconsin price series has served as the basic formula price used to move or change the level of all Federal order milk prices. The M-W price has also served as the guide for determining if the milk price support objective set by Congress or the Secretary of Agriculture has been realized.

The M-W price series is the average price paid for Grade B milk (which can only be used for processing dairy products such as cheese and butter) by Minnesota and Wisconsin processing plants. However, the volume of Grade B milk produced in Minnesota and Wisconsin has declined to where the M-W price series may not reliably reflect the forces of supply and demand for this milk.

In 1989, the GAO concluded that alternatives to the M-W price series should be evaluated and implemented. It recommended two options:

- a product formula based on the market prices for butter, NFDM, and/or cheese; and
- a competitive price for Grade A and Grade B milk.

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[5] A regulation issued by the Secretary of Agriculture specifying minimum prices and conditions under which milk can be bought and sold within a specified geographic area.

Emerging Technology

The dairy industry will be among the first to adopt many of the newly emerging technologies from the biotechnology era. Considerable controversy surrounds the potential use of these technologies. This is especially true of bovine somatotropin (bST), now undergoing review by the Food and Drug Administration (FDA). Concerns about food safety, animal safety, the manufacturing process to produce the technology, and the economic impacts on the dairy industry have all coalesced to make bST the focus of a controversy of unprecedented magnitude in the dairy industry.

A number of actions have already been taken to slow or stop the use of bovine somatotropin. Two States have declared a moratorium on the use of the technology if approved by FDA. Four States have enacted or are considering enacting labeling requirements on dairy products produced from bST-supplemented milk. And consumer groups have successfully pressured some large retail food stores not to market dairy products produced with this technology.

The next chapter provides information and an analysis of the issues relevant to this technology. Subsequent chapters discuss other major emerging technologies that should become available in this decade for the dairy industry.

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2. U.S. General Accounting Office, *Milk Marketing Orders: Options for Change*, GAO/RCED-88-9 (Washington, DC: March 1988).
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Chapter 3

An Emerging Technology: bovine Somatotropin

The U.S. dairy industry has a rich history of technological advances underpinning steady and significant increases in the efficiency and economic returns of milk production. Progress in biotechnology and information technology will carry this trend into the 1990s. Through the application of biotechnology, farmers will be able to manipulate to an unprecedented degree herd reproduction, genetics, and the physiological variables that affect their animals' productive efficiency.

Genetically superior (more productive) animals are distinguished by their regulation of nutrients; new concepts of how this occurs have recently been established (6,10,11). Potentially one of the most significant of the new biotechnologies is bovine somatotropin (bST). Recent work has demonstrated that somatotropin exerts a key control over nutrient use. When administered exogenously, it markedly improves the productive efficiency (milk per unit of feed) in lactating cows. It does so by coordinating the metabolism of body tissues such that more nutrients are used for milk synthesis.

However, a number of questions involving human safety, animal safety, economic concerns, and ethics surround bST. Lay articles focusing on human and animal safety issues of bST imply that little research has been done. In fact, the scientific literature on bST contains at least 1,000 studies involving some 10,000 dairy cows.[1] This chapter provides an overview of bST technology and the concerns surrounding it. It assesses the validity of these concerns based on current scientific knowledge and on dairy industry trends.

STATE OF THE ART

Somatotropin, a hormone, was discovered about 50 years ago. Initial investigations showed that when rats were injected with a crude pituitary extract, growth rate was increased (only later did scientists discover that milk yield of lactating animals increased as well). This extract factor was called somatotropin from the Greek derivation meaning "tissue growth." Based on this derivation, somatotropin is sometimes referred to as growth hormone or GH.

Somatotropin is produced by the anterior pituitary gland, a small gland located at the base of the brain. Like any hormone, it is transported in the bloodstream to the various body organs where it exerts its biological effects. In effect, it acts as a chemical link between different cells and organs of the body. The term "hormone" has taken on negative connotations in recent times, primarily due to steroid abuse by athletes. However, the chemistry of hormones is as diverse as their biological functions. For example, vitamin D (with which pasteurized milk is fortified) is a steroid hormone.

Somatotropin is also a protein, unlike steroids, which are nonprotein hormones. Like all proteins, it is composed of amino acids. (There are 20 different amino acids, which combine in specific sequences to form some 10,000 different proteins in the body. Amino acids are analogous to letters in an alphabet, which combine to form a diverse vocabulary of words.) The amino acid sequence of somatotropin is known for many species, including cattle (41,79). Bovine somatotropin can be either 190 or 191 amino acids long and either of two different amino acids (leucine or valine) occupy position number 126 in the sequence (80). Thus, four different variants of bST are produced naturally. Typically, the pituitary produces equal amounts of the 190 and 191 amino-acid bST. About two-thirds of the total bST produced has leucine at position 126, while the remaining one-third has the amino acid valine at position 126.

Artificially introduced somatotropin must be injected to be biologically active. If somatotropin is given orally, it is broken down by digestive track enzymes to amino acids for absorption. This is true for all dietary proteins and large protein hormones in all species. Just as human diabetics must take insulin injections (insulin, another protein hormone, is also inactive if taken orally), humans deficient in somatotropin must take injections of *human* somatotropin (hST). Studies have demonstrated that when fed to rats, bST was inactive even at a daily dose (units/

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[1] Because of the large quantity of research on bST, this chapter will mainly cite review articles of these studies.

body weight) equivalent to 2.3 million times what a human would be exposed to in five 8-ounce glasses of milk (38,67).

Somatotropin is referred to as "species limited" in the scientific literature. This means that there are differences in the ability of somatotropin from one species to elicit biological effects when injected in other species. To have a biological effect, a protein hormone must first bind to a specific receptor located on the cell surface. The amino acid sequence of somatotropin gives it a unique three-dimensional shape, which determines whether the protein will be able to bind to tissue somatotropin receptors and elicit a biological response.

Some 25 years ago it was discovered that certain types of human dwarfism were due to an inadequate pituitary production of somatotropin. Because hST was scarce, physicians conducted an extensive series of studies in which patients were treated with injections of bST. These clinical studies uniformly demonstrated that bST does not elicit any of its normal biological actions in humans even if injected (20,38,41,79). Somatotropin isolated from the pituitary glands of sheep, pigs, and whales was also ineffective in humans. Biological activity in humans is only observed if somatotropin from primates is used.

The reason for bST's lack of effect in humans became clear when its amino acid sequence was identified; the sequence of bST, which gives it its three-dimensional shape, differs by about 35 percent from that of hST (79). Thus, bST is not able to bind to the somatotropin receptors of human tissues (36,38). In contrast, ovine somatotropin and bST differ in only one amino acid position so bST is biologically active if given to sheep.

Recombinantly derived bST products differ slightly from the bST produced by the pituitary gland in that a few extra amino acids may become attached to the end of the bST molecule in the manufacturing process. The number of extra amino acids varies from 1 to 8 depending on the particular manufacturing process (38). For some manufacturing processes, no additional amino acids are produced. Some claim that for processes that produce extra amino acids, and the fact that recombinantly derived bST is produced by bacterial ribosomes, it renders the product hyperpotent to cows and dangerous to humans (23,46,64). However, the additional few amino acids on the end of the protein do not alter the biological activity of bST in dairy cows or the lack of activity of bST in humans because the three-dimensional shape of the active part of the molecule is not changed (36,79). This shape, moreover, is determined by the *sequence* of amino acids, not by whether or not bacterial ribosomes were used for the synthesis.

The first bST research with lactating cows was reported in 1937 by Russian scientists (1). With advances in protein chemistry, somatotropin preparations gradually improved in purity and several dozen studies have since been conducted with dairy cows. Particularly significant were a series of studies in the 1940s by scientists in the United Kingdom (81) and later studies by Brumby and Hancock (13) and Machlin (49).

Prior to the 1980s, bST research progress remained slow for two reasons. First, bST availability was limited to what could be extracted from the pituitary glands of slaughtered animals. Thus, only a small number of cows could be treated for short-term studies. Second, because bST was thought to act by acutely stimulating the use of body fat reserves, scientists believed it would work only in fat cows with a low milk yield. Thus, only low producing cows (generally less than 7 kilogram (kg) milk/day) were studied. It was assumed that bST would cause ketosis[2] and adverse health effects in high producing cows.

Scientists at the National Institute for Research in Dairying in England, and others at Cornell University, in the late 1970s began to work on bST. Both groups concluded that the physiological basis for genetically superior cows (i.e., those more efficient in milk production) was better use of absorbed nutrients (10,12). Based on new concepts of how animals regulate the use of nutrients (7), both groups hypothesized that somatotropin could play a key role in nutrient regulation and that the previously proposed mechanism of action (acutely stimulated use of body fat) was wrong. Over the last decade these concepts have been applied to research with somatotropin and the biology of nutrient use during growth, pregnancy, and lactation for many species.

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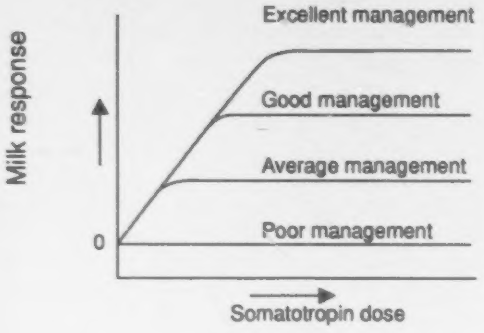
[2] A metabolic disorder that occurs when production of ketones exceeds the ability of the body to use them. Occurs in dairy cows when the need for glucose exceeds the production of glucose.

Figure 3-1—Effect of Quality of Management on Milk Response of Dairy Cows Receiving bovine Somatotropin



SOURCE: D.E. Bauman, "Bovine Somatotropin: The Cornell Experience," Proceedings of the National Invitational Workshop on Bovine Somatotropin, pp. 46-56, USDA Extension Service, Washington, DC, 1987.

Initial investigations with cows used pituitary-derived bST. After landmark breakthroughs in biotechnology, in 1982, the Cornell scientists conducted the first study with dairy cows using recombinantly derived bST produced by Monsanto Co. and Genetech Co. (8). Since that time the quantity and scope of research with bST has increased exponentially.

PRODUCTION RESPONSE

Quality of management will be the major factor affecting the magnitude of lactation response to bST (4,16,17,57). This concept is illustrated qualitatively in figure 3-1. Across 45 field trial studies conducted in the United States, Europe, and Africa a correlation of 0.58 was observed between pretreatment group milk yield (an indication of management quality) and kg milk response to bST (57). A similar relationship between management quality and gains realized is observed for other technologies, such as artificial insemination (AI) with semen from superior sires.

Facets that contribute to the quality of the overall management program include the herd health program, milking practices, nutrition program, and environmental conditions. Inadequate management can result in a near zero response to bST supplement (51,52,57). McCutheon et al. (51) studied bST's effects as the quality of herd nutritional management varied over the course of the 26-week treatment period. Cows were fed only pasture, and milk responses to bST were greatest (+18 percent) in the spring when pasture supply was adequate, declined to zero during the summer drought, and were again significant during the fall. As this illustrates, bovine somatotropin is not magic. If cows are given an inadequate amount of feed or fed a diet that is not nutrient-balanced, the magnitude of the response to bST will decrease accordingly (see figure 3-1).

While the milk response to bST on an individual farm will vary according to quality of management, a reasonable expectation is that successful adopters would experience an average gain in productivity of 12 percent. This gain in productivity could lead to substantial savings in dairy cattle feed nationally. Assuming 100-percent adoption and milk production at 1988 levels (26), then decreased cow numbers (10.7 percent) and increased productive efficiency would translate into annual savings in dietary energy equivalent energetically to 2.5 x 10^9 kg of corn grain. Annual savings in dietary protein supplements would be equivalent to 5.6 x 10^7 kg of soybean meal (see table 3-1). These savings in feedstuffs represent

Table 3-1—Impact of bST on Animal Numbers, Feed Requirements, and Waste Production of Dairy Cows To Achieve 1988 U.S. Milk Production[a]

Variable	Impact of bST[b]
Animals:	
Cow numbers	Decrease by 10.7%
Milk yield per cow	Increase by 12.0%
Feed:[c]	
Energy equivalent as corn grain	Decrease by 2.5 x 10^9 kg
Protein supplement equivalent as 44% soybean oil meal	Decrease by 5.6 x 10^7 kg
Waste:	
Manure[d]	Decrease by 6 x 10^9 kg
Urine[e]	Decrease by 8 x 10^9 L
Urinary nitrogen[e]	Decrease by 8 x 10^7 kg
Methane[f]	Decrease by 8 x 10^{10} L

[a] U.S. 1988 milk production values were 10.24 x 10^6 cows, 6,460 kg milk per cow, and 66 x 10^9 kg total milk production (26).

[b] Assumed 100-percent adoption and that use would increase average annual milk yield per cow by 12 percent. If commercially approved, expected impact would be less because technology rarely achieves 100-percent adoption.

[c] Based on nutrient requirements for dairy cows averaging 650 kg body weight and producing milk of 3.5-percent fat content (54).

[d] Based on an average diet composition of 1.62 Mcal net energy/kg, a diet digestibility of 65 percent, and fecal dry matter of 16 percent (72).

[e] Based on a daily urine production of 20 L per cow with 1-percent nitrogen in urine (72).

[f] Assumed that methane production represents 5 percent of gross energy intake (72).

SOURCE: D.E. Bauman, "Bovine Somatotropin: Review of an Emerging Animal Technology," commissioned background paper prepared for the Office of Technology Assessment, Washington, DC, 1990.

maximal estimates because commercial adoption of new technology is rarely 100 percent (see ch. 5).

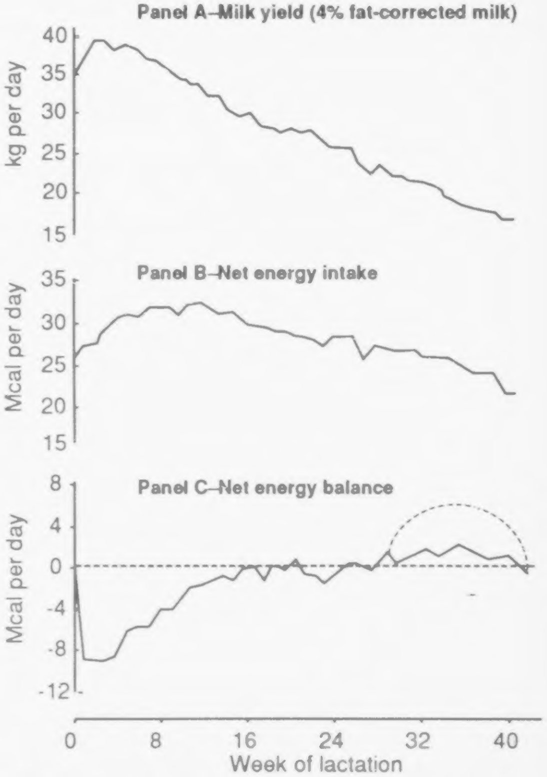
Milk yield gradually increases the first few days of bST treatment, peaking at about the sixth day (37,56). A maximum milk response is achieved at a bST dose (daily injection) of about 30 to 40 milligrams (mg) per day; no further increase occurs even at doses several-fold higher. Most production trials have used a bST dose between 10 to 50 mg per day. Exogenous bST must be introduced every day (by injection or via a prolonged-release formulation) in order to maintain an augmented milk response. This is because bST is cleared rapidly from the bloodstream and is not stored in the body. Removal is by protein breakdown to amino acids—a normal body function. Several prolonged-release formulations have been developed and are administered by subcutaneous injection at intervals ranging from 2 to 4 weeks (17).

Response to bST varies according to stage of lactation (see figure 3-2). In general, the milk response is small or negligible when bST is administered in early lactation (the interval immediately postpartum, prior to peak milk yield) (4). The biological basis for this low response relates to the nutrition/endocrine status of the animal during this interval. In contrast, substantial increases in milk yield occur when bST is administered after peak yield of milk is attained. Lactational responses to bST have been reported for all dairy breeds examined, including North American and European breeds as well as Murrah buffalo, and for animals of different parity (lactation number) and genetic potential (16,17,56).

Marked improvement in persistency of lactation occurs in cows receiving bST (16,17,56). The greater overall milk yield with bST supplementation occurs in part because of an immediate increase in milk yield, but mainly because of a reduction in the normal decline in milk yield that occurs as lactation progresses.

Cows treated with bST show a range of responses. In a few instances this has been cited as evidence of individual variation in response. However, this is misleading. All studies with bST have shown that the yield variations within bST-supplemented groups is similar to that of untreated groups (5,57). Thus, to a large extent, all cows in a herd respond to bST in a fairly similar manner. The bST-supple-

Figure 3-2—Temporal Pattern of Milk Yield, Net Energy Intake, and Net Energy Balance During a Lactation Cycle in Dairy Cows



Cows averaged 9,534 kg milk (21,000 lbs) over the first 305 days of lactation. Typically, daily milk yield peaks during the first month after parturition (birth of the calf) and then progressively decreases through the remainder of the lactation cycle (Panel A). The rate of this decline in daily milk yield is referred to as the persistency of lactation. Typically, voluntary feed intake increases gradually over the first few weeks of lactation and peaks about 6 to 10 weeks after parturition (Panel B). Dairy cows are generally in negative energy balance during the first portion of the lactation cycle (Panel C). During the first month of lactation for these cows, the body reserves being utilized (i.e., net energy deficit) were energetically equal to about one-third of the milk produced. Under normal management conditions the daily cow is overfed (positive energy balance) during the last third of lactation to allow for replenishment of body energy stores needed to support the next lactation cycle (dashed line, Panel C).

SOURCE: D.E. Bauman and W.B. Currie, "Partitioning of Nutrients During Pregnancy and Lactation: A Review of Mechanisms Involving Homeostasis and Homeorhesis," *J. Dairy Sci.* 63:1514-1529, 1980.

mented cow that "appears" to be a low responder simply matches the low producing control cow.

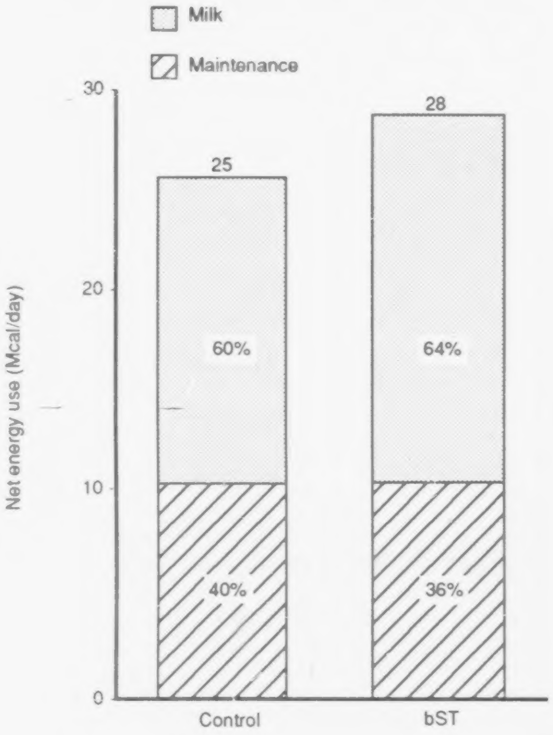
NUTRIENT REQUIREMENTS

Nutrient requirement tables are unchanged for bST-supplemented dairy cows (11,16). The basis for this is two-fold. First, digestibilities of dry matter, carbon, nitrogen, and energy are not altered when lactating cows are receiving bST. Second, bioenergetic studies have demonstrated that bST does not alter energy expenditure for maintenance, or for the synthesis of a unit of milk. Nutritional needs for maintenance, milk production, pregnancy, and to replenish body reserves over a lactation cycle for a cow producing 10,000 kg milk per year are the same regardless of whether she received bST or not.

No special diets or unusual feed ingredients are needed to obtain a milk response to bST: substantial milk responses have been observed on diets ranging from pasture to forage concentrates.[3] Overall, however, the dairy cow receiving bST has a greater total nutrient requirement because she is producing more milk. She has a higher productive efficiency because a larger proportion of her total nutrient intake is used to make milk (see figure 3-3).

Voluntary intake of feed increases in bST-supplemented dairy cows, beginning after a few weeks of bST supplementation, and persisting throughout the interval of bST use. This has been consistently observed across a wide range of diets (16,17,56). Overall, cows supplemented with bST adjust their voluntary intake in a predictable manner related to the extra nutrients required for the increased production of milk. The magnitude of increase in feed intake is dependent on the response in milk yield and the energy density of the diet (17). It is expected with current feed costs that use of bST for dairy cows will, on average, lead to a predictable increase in the energy density of the diets used (increased ratio of concentrate to forage). This is because income over feed cost increases with level of milk production even though the cost for higher energy ingredients is greater. However, as noted, bST increases milk yield even when pasture is the only dietary ingredient.

Figure 3-3—Efficiency Gains by Reduction in the Proportion of Nutrients Used for Maintenance[a]



[a]For this example, the hypothetical control cow produced 6,818 kg (15,000 lb) of milk in a lactation and use of bST increased milk yield by 20 percent

SOURCE: D.E. Bauman, "Biology of Bovine Somatotropin in Dairy Cattle," *Advanced Technologies Facing the Dairy Industry: bST*, Cornell Cooperative Extension Animal Science Mimeograph Series #133 (Ithaca, NY: Cornell University, 1989), pp. 1-8.

BOVINE REPRODUCTIVE PERFORMANCE

Of special interest are the effects of bST on reproductive variables such as conception rate (services per conception), pregnancy rate (proportion of cows becoming pregnant), and days open (days from parturition to conception). Normally, variation in reproduction variables is large. Effects of bST supplementation are small enough that large data sets are needed to allow definitive conclusions. Several reviews have summarized many of the studies on reproduction variables (28,55,59). In general, these summaries indicate that bST supplementation results in a decrease in pregnancy rate but that conception rate is not altered. For example, Ferguson and Skidmore (28) found that pregnancy rate (n >3,000 cows) was 89.2 percent for controls and 81.2 percent for bST-supplemented cows (bST dose ranged from 5 to >200 mg per day). Days open increased a few days in bST-supplemented cows according to most studies.

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[3] Use of somatotropin for growing animals will require modification of the maintenance and growth components of the nutrient requirement tables because of the shift in the type of growth (increased protein, decreased lipid).

The studies that identified changes in pregnancy rate and days open for bST-supplemented cows followed management practices geared to achieve a 12- to 13-month calving interval. Thus, period of breeding (commencing 50 to 60 days postpartum) would generally have coincided with the early period of bST supplementation when milk yield had increased but before voluntary feed intake had increased. It is well established that decreased pregnancy rate and increased days open are associated with increases in milk yield (15). This is because of the inverse relationship between level of milk production and energy balance that typifies the early stage of lactation. Ferguson and Skidmore (28), for example, found the decrease in pregnancy rate to be related to the increase in milk yield rather than the dose of bST when they analyzed their multistudy data by controlling for confounding factors. Hard et al. (35) summarized a series of studies that had a similar design and found that days open increased by 5 days in the bST-supplemented group; however, when data were stratified by level of milk production, days open did not differ between controls and bST-supplemented cows (35). Thus, effects of high milk yield on reproductive performance are the same whether or not the high yield was due to the use of bST.

Calving interval for optimum economic return for U.S. dairy farms will probably increase with bST supplementation. Although conventional wisdom has been that a 12- to 13-month calving interval maximizes profit, many managers of high producing dairy herds indicate that their calving interval is longer (6). In the case of bST supplementation, not only does milk yield increase, but persistency of lactation is also improved. Thus, it is logical that the calving interval for optimum economic return may be substantially increased when bST is used. Ferry (29) modeled the effects of a 12- and 14-month calving interval on a herd basis and concluded that with bST use, income over feed cost was considerably increased with a 14-month calving interval. More extensive modeling, which included factors such as veterinary costs and replacement values, yielded a similar conclusion (70).

Extending the calving interval also has some benefits from the standpoint of the physiology of the cow. In the case of reproduction, increasing the calving interval improves conception rate (71), probably as a consequence of the nutritional status of the cows as discussed earlier. In addition, the majority of health problems and veterinary costs for dairy cows occur during the first 45 days postpartum (24). Thus, increasing the calving interval reduces health problems and costs on an annual basis for a herd and over an individual animal's lifetime.

Optimum calving interval with bST use probably will be different in the United States than in other countries, particularly countries that have a seasonal supply of feedstuffs and a beef industry largely based on the offspring of dairy cows. Thus, the actual calving interval that optimizes economic return will vary according to a number of management and economic factors; still, a major determinant will be the magnitude of milk response and the increased lactation persistency that occurs with bST use.

Genetic evaluation of sires might be affected by use of bST if an interaction between genotype and the milk response to bST occurs, or if bST is inappropriately used to manipulate sire proofs. Several studies have concluded that no evidence exists of a genotype-response interaction in bST-supplemented cows (32). Sire evaluations involve the comparison of the performance of a bull's daughters with the performance of their contemporary herdmates. A bias in sire evaluations can occur (and has) if a farmer gives preferential treatment to the daughters of a particular sire that he hopes to market commercially (25). Potential for bias from the use of bST is similar and can be handled by properly coded records and/or use of AI-proven sires (25,32). With proper coding of records, bST-treated daughters could be compared only with herdmates that had also received bST supplement. Similarly, when the sire is evaluated with AI records, many more daughters in a large number of herds will be involved; thus the chance for bias is negligible.

MILK AND MEAT COMPOSITION

Gross composition of milk (fat, protein, and lactose content) and meat has been examined in most bST production trials, and is not substantially altered by bST supplementation (3,16,50,56,75). There can be minor changes, primarily in fat content of milk, during the first few weeks of bST supplementation as the cow's metabolism and voluntary feed intake adjust. However, these changes are temporary and minor when compared with variations that normally occur over a lactation cycle. Whereas the lactose content of milk is relatively constant, the content of fat, and to a lesser extent protein, normally varies widely due to many factors including genetics, breed, stage of lactation, age, diet composition, nutritional status, environment, and season (48). These factors affect the fat and protein content of milk in the same manner in bST-supplemented and nontreated cows (3,16,56). The meat derived from treated cows has a lower fat content but is otherwise identical (53).

The temporary shift in milk fat that can occur during the first few weeks of bST supplementation relates to nutritional status (11,16,56). Cows in negative energy balance produce milk with a higher fat content due to a greater reliance on lipids mobilized from body fat stores. Milk fat content is most likely to increase when bST supplementation is initiated in the first 100 days postpartum, when cows are typically in a lower energy balance. However, the negative energy balance typical of this period (and especially of the first 8 weeks of lactation) is far in excess of that associated with bST supplementation.

The lipid composition affects the milk's nutritive value, flavor characteristics, and manufacturing properties. Studies demonstrate that fatty acid composition and cholesterol content of milk are not altered by bST (3). Cows that are in negative energy balance (as occurs early in lactation) shift milk fat composition toward longer chain, unsaturated fatty acids whether or not they receive bST supplementation. In addition, the same fatty acid composition changes are observed in untreated and bST-supplemented cows as lactation progresses.

Composition of milk proteins has been examined in at least a dozen studies because of the impact on functional properties of milk used in the manufacturing of dairy products (3,75). These studies have demonstrated that the content and composition of casein (α-casein, β-casein, k-casein) are not altered by bST supplementation; and that casein as a percent of true protein is either unchanged with use of bST or shows a small numerical decrease (often nonsignificant). One short-term study reports a small increase in α-lactalbumin content of milk in bST-supplemented cows but this was not observed in long-term studies. The nonprotein nitrogen (NPN) content of milk from bST-supplemented cows should vary with nutritional status just as it does in untreated cows. Some countries routinely test NPN levels in bulk milk as a management tool for farmers to evaluate the protein adequacy of their nutritional program (61).

Mineral content of milk from bST-supplemented cows has been examined in short- and long-term studies involving large numbers of animals (3,75). Results have uniformly demonstrated that bST does not alter ash (total mineral content) or any nutritionally important mineral. Only one published report exists on the vitamin content of milk, but milk from bST-supplemented cows did not differ in content of any vitamin (vitamin A, thiamine, riboflavin, pyridoxine, vitamin B_{12}, pantothenic acid, and choline) except for biotin, which showed a slight increase (75). The increase in biotin content of milk is too small to be considered a benefit; biotin, a member of the b-vitamin family, is widely distributed in plant and animal food products and is also synthesized in the intestine of humans.

Manufacturing characteristics of milk have been investigated in a smaller number of studies but results have consistently demonstrated that milk from bST-supplemented cows does not differ from milk of untreated cows (3,75). Characteristics studied include freezing point, pH, alcohol stability, thermal properties, proteases, lipases, susceptibility to oxidation, and sensory characteristics, including flavor. Similarly, no differences were observed in cheese-making properties, including starter culture growth, coagulation, acidification, and syneresis, or in the yield, composition, or sensory properties of the various cheeses.

Minor constituents of milk include hormones such as estrogen, progesterone, glucocorticoids, thyroid hormones, prolactin, and growth factors. Trace concentrations of bST also normally occur in milk and meat but this concentration is not appreciably altered when cows receive exogenous bST (38,53,65,75). The level of bST in milk is only a small fraction of the blood concentration. Only when blood levels are increased about 30-fold by a substantial dose of bST is there a small, but significant, increase in milk concentrations of bST

(65). This lack of an appreciable change in milk concentration of bST when exogenous bST is administered is expected, given that mammary epithelial cells do not have receptors for somatotropin (19). Pasteurization of milk destroys 85 to 90 percent of immunoreactive bST (33).

Some part of the biological actions of somatotropin may be mediated by insulin-like growth factor I (IGF-I). IGF-I, a protein hormone and member of the somatomedin family, normally occurs in trace levels in milk. The concentration of IGF-I is higher in cows' milk (3 to 10 parts per billion) than in human milk (1 to 3 parts per billion). Administration of bST to dairy cows results in an increase in the amount of IGF-I in milk (by 2 to 5 parts per billion), but the levels are still within the range typically observed in early lactation of untreated cows (31,38,65,75). There is approximately twice as much IGF-I in meat of treated cows (2).

Studies with laboratory animal models have demonstrated that IGF-I, like bST, has no biological activity if administered orally (38). It is digested into its amino acid, di- and tripeptide constituents by gut enzymes. Similarly, no evidence exists that fragments of IGF-I are biologically active in humans, nor is there evidence of systemic biological effects in humans from any IGF-I absorbed intact. The amounts of IGF-I that might potentially be ingested in food products from treated cows are orders of magnitude less than those required to produce such effects (53).

The amount of IGF-I ingested in one liter of milk from bST treated cows approximates the amount of IGF-I in human saliva swallowed daily by adults (31). Young children and infants already ingest IGF-I in regular cows' milk. The importance of the additional amount of IGF-I in milk from bST-treated cows—whether it has a local effect on the esophagus, stomach, or intestine of infants—is unknown (53). However, most infants are either breast fed or fed commercially prepared infant formulas; the heat treatment used in the manufacture of these formulas inactivates approximately 90 percent of IGF-I.

MECHANISMS OF ACTION

Somatotropin regulates the use of absorbed nutrients. When milk production is increased, extra nutrients are needed by the mammary glands to provide the raw materials and energy to make milk. Somatotropin coordinates the metabolism of various body organs and tissues in a manner that supports the increased nutrient use by the mammary glands. These coordinated adjustments in tissue metabolism involve all nutrient classes—carbohydrates, lipids, proteins, and minerals (see table 3-2), and are due to the direct action of somatotropin on tissues (e.g., liver and adipose). The adjustments made are characteristic of metabolic changes needed to support lactation in all mammals (11,56,77).

Glucose metabolism illustrates the coordinated manner in which bST alters tissue processes. Glucose is a carbohydrate used as an energy source by many tissues and as a raw material for milk synthesis (primarily for production of milk sugar). Nearly all of a cow's daily glucose requirement is made by the liver and the mammary glands typically use about 85 percent of the total. With bST-supplementation, the uptake of glucose by the mammary glands increases in a manner parallel to the increases in milk production. This increased use of glucose for milk synthesis is accommodated by whole-body adjustments which include increase glucose production by the liver and reduced glucose use for energy by other body tissues. In part, these adjustments occur because bST alters the response of tissues to acute signals (e.g., insulin), thereby allowing a greater allocation of glucose for milk synthesis while still maintaining normal body functions. Without such adjustments in metabolism, initiation of bST supplementation would cause the glucose use to exceed that which is available, resulting in ketosis and death. Ketosis from bST supplementation has not been observed in the hundreds of studies performed, even in tests where bST resulted in increased milk production of 40 percent or more.

Lipid metabolism provides another example of the coordination which occurs with bST supplementation. The adjustments in tissue lipid metabolism depend on the nutritional status of the cow at the time bST-supplementation is initiated. Normally, if a cow's nutrient intake is greater than her requirements, the excess nutrients are used to make body fat. BST administration causes adipose tissue to reduce its use of nutrients to synthesize body fat and allows for reallocation of these nutrients to support increased milk production. A different metabolic adjustment occurs if the cow's nutrient intake is equal to or less than her requirements. In this instance, somatotropin directs adipose tissue to mobilize deposits of body fat so that these energy reserves can be used to support increased milk

Table 3-2—Effect of bST on Specific Tissues and Physiological Processes in Lactating Cows[a]

Tissue	Process affected during first few days and weeks of supplement
Mammary	↑ secretory activity and maintenance of mammary glands
	↑ blood flow and nutrient uptake
	↑ synthesis of milk with normal composition
Liver	↑ production of glucose
	o response to acute signals (e.g., insulin) that allow for greater glucose production
Adipose	↑ mobilization of fat stores to meet needs for increased milk production if nutrient intake is inadequate
	↓ use of nutrients for fat storage so that they can be used for increased milk production if nutrient intake is adequate
	o response to acute signals (e.g., insulin and other hormones that affect lipid metabolism) that allows for synthesis and breakdown of body fat reserves to be coordinated with changes in use and availability of nutrients
Muscle	↓ uptake of glucose
Pancreas	ø insulin and glucagon secretion reponse to changing glucose levels
Kidney[b]	↑ production of 1,25 vitamin D_3
Intestine[b]	↑ absorption of Ca, P and other minerals required for milk
	↑ ability of 1,25 vitamin D_3 to stimulate calcium binding protein
	↑ calcium binding protein
Whole body	↓ use of glucose by some organs so more can be used for milk synthesis
	↑ use of fat stores for energy if nutrient supply is inadequate
	↓ use of nutrients to make body fat if nutrient supply is adequate
	ø insulin and glucagon clearance rates
	ø energy expenditure for maintenance
	↑ energy expenditure consistent with increase in milk yield (i.e., heat per unit of milk not changed)
	↑ cardiac output consistent with increases in milk yield
	↑ productive efficiency (milk per unit of energy intake)

[a] Changes (↑=increased, ↓=decreased, ø=no change, o=change) that occur in initial period of bST supplement when metabolic adjustments occur to match the increased use of nutrients for milk. With longer term treatment, voluntary intake increases to match nutrient requirements.

[b] Demonstrated in nonlactating animals and consistent with observed performance in lactating cows.

SOURCE: D.E. Bauman, "Bovine Somatotropin: Review of an Emerging Animal Technology," commissioned background paper for the Office of Technology Assessment, Washington, DC, 1990.

production. In both situations, these adjustments involve alterations in adipose tissue response to acute signals (e.g., insulin and other hormones that affect lipid metabolism) thereby allowing the use of body fat reserves to be coordinated with changes in the animal's need for, and availability of nutrients. Over time, bST teated cows gradually increase their feed intake so that stores of body fat are replenished during a lactation cycle. This replenishment occurs under a wide range of dietary conditions (11,16,17). If these adjustments in lipid metabolism did not occur, cows would become emaciated, decrease their milk production, and be less efficient in their use of feed for milk production. These effects have not been observed; cows administered bST have demonstrated increased milk production and improved feed efficiency.

In addition to the direct metabolic effects that bST coordinates, somatotropin indirectly affects the mammary gland via its impact on other controlling compounds (e.g., somatomedins such as IGF-1). Effects include increased cellular rates of milk synthesis and improved maintenance of secretory cells (i.e., slower rate of cell loss). The net result is that bST-supplemented cows have higher daily milk yields and produce higher levels of milk throughout the lactation cycle. Over the years, selection of higher producing dairy cows has resulted in the same improvements. Thus, it is not surprising that cows that produce high levels of milk have higher circulating levels of naturally produced somatotropin than do cows that produce low levels of milk (6).

BOVINE HEALTH AND STRESS

Catastrophic health effects have been postulated to occur with bST supplementation of dairy cows. Ketosis, fatty liver, and chronic wasting have all been proposed as possible side-effects of bST use (12,43). Crippling lameness, milk fever (a feverish disorder following parturition), mastitis (inflammation of the udder), infertility, heat intolerance, sickness, suffering and death are recent additions to the list of adverse health claims (23,30,45,62,63,64). These postulated catastrophic effects were not based on actual data but rather on the presumption that bST caused the mobilization of lipids from body fat reserves and/or overtly caused stress.

Metabolic disorders, if they occurred, would most likely manifest themselves during the first few days of bST use. None of the above catastrophic health effects have been observed in any of the short-term or long-term studies with dairy cows going back to the first bST study in 1937. They were not observed in chronic toxicity studies (22,55), or in acute toxicity studies where dairy cows were given 30,000 mg of bST over a 2-week period, an amount approximately equal to what would be administered in four lactations (about 40 months) (78). Nor were adverse effects observed in studies where inadequacies in the overall quality of the management program resulted in negligible milk responses to bST supplementation. An increase in ketones (an indicator of subclinical ketosis) was reported in one earlier study involving two cows given bST for 9 or 10 days (42). However, that pituitary-derived preparation was contaminated with other hormones (42,44), and this work has not been verified in acute or chronic studies using larger numbers of cows treated for longer periods with a wider dose range of purified bST (11,16,59,78).

It also has been postulated that somatotropin will reduce resistance to infectious and contagious diseases and thereby increase sickness and suffering in dairy cows (23,30,63,64). Incidence of disease is generally very low in dairy cows and a thorough evaluation of these claims will require extensive summarization across studies to obtain a large data set. However, none of the hundreds of bST studies reported lower milk yield or decreased productive efficiency, both of which are associated with any increase in sickness and suffering. On the contrary, somatotropin plays a key role in several aspects of maintaining immune competence (39). Immunity and disease resistance are compromised in somatotropin-deficient laboratory animals and humans and somatotropin supplementation enhances immune competence in both groups. Such studies have not yet been extended to lactating cows, but it has been demonstrated that bST supplementation had a beneficial effect on cows' recovery from experimentally induced *E. coli* mastitis (14).

Stress is more difficult to evaluate, but several indices exist that demonstrate no stress effects due to bST. Dairy cows that are stressed produce less milk less efficiently and expend more energy as heat than expected. All of the several hundred studies of bST in the scientific literature report increased milk yield and productive efficiency. The duration of bST use in these studies has ranged from a few weeks to at least four successive lactations. While numerous physiological variables have been monitored to assess stress and have been shown not to change, nothing illustrates the normalcy of bST-supplemented cows as effectively as the persistent gains in milk yield and productive efficiency throughout the treatment period. Recent studies spanning positive-to-negative energy and nitrogen balances, moreover, have clearly demonstrated that bST has no effect on the energy expended for maintenance or for the synthesis of a unit of milk (40,68,73).

Subtle health effects require examination of "large numbers of animals treated under a range of environmental and management conditions" (21). A complete summary of individual studies done throughout the world is beyond the scope of this review. Many have appeared as abstracts in the last 2 years and have not yet been published as full-length papers. However, these summarizations are required of companies seeking the Food and Drug Administration (FDA) approval and are used by regulatory agencies in their evaluation. Phipps (59) summarized a substantial portion of the studies conducted through 1988. This review showed that the indices of animal health for bST-supplemented animals were similar to these for controls and were consistent with values reported in the literature for untreated cows at a similar level of milk production. Variables examined included physical examinations, bone radiography, blood chemistry, metabolic disorders, subclinical ketosis, udder health, and welfare of the treated cows as well as the health, growth, and performance of their offspring.

Subtle effects on the incidence and duration of mastitis are of special interest. Major factors affecting the incidence of mastitis include milking management and herd health programs. However, the incidence of mastitis and milk somatic cell counts are also positively correlated with milk yield (58,60,69). Effects are quite small and amount to an annual increase of approximately 0.4 cases/cow for each 1,000 kg genetic gain in milk yield. Thus, it will take very large numbers of cows to detect and evaluate whether subtle effects, independent of milk-yield response, occur with the use of bST. Phipps (59) summarized the incidence of clinical mastitis across studies totaling over 1,300 cows and found that the relative incidence of mastitis was not affected by bST supplementation. Ferguson (27) likewise summarized eight studies reporting mastitis and found that there was no indication that bST was associated with increased mastitis infections.

Concern has been raised that even the small increased incidence of mastitis from higher producing animals will increase the use of antibiotics in cows. However, Burvenich et al. (14), reported that recovery time from experimentally induced mastitis is reduced in cows receiving bST supplement; it will be of interest to learn whether the same beneficial effects of bST supplement are observed for naturally occurring cases of mastitis under field conditions.

ONFARM ENVIRONMENTAL POLLUTION

Environmental pollution is reduced with bST use as a result of the gain it yields in productive efficiency. Substantially less feed is required to produce the same quantity of milk. This correspondingly reduces the use of fertilizer and other inputs associated with producing, harvesting, processing, and storing of dairy feedstuffs.

Total U.S. animal fecal waste could also be reduced by as much as 6 x 10^9 kg assuming 100 percent adoption and production of milk at 1988 levels (see table 3-1). Similarly, the productive efficiency gains with use of bST supplement could result in an annual reduction of 8 x 10^9 liters urine and 8 x 10^7 kg of urinary nitrogen for the total U.S. dairy herd (see table 3-1).

Ruminants also produce methane, a gas having a strong greenhouse effect. Ruminants and animal waste account for about one-fifth of total worldwide methane emissions (18), with cattle accounting for about three-fourths of the livestock methane emissions or about 15 percent of total global methane emissions (47). Because of the gain in productive efficiency when bST is used, methane production by dairy cows could be reduced by as much as 5.5 percent per unit of milk produced. For milk production at 1988 levels, this amounts to an annual reduction of 8 x 10^{10} liters of methane in the United States (see table 3-1).

It has been suggested that even though total environmental pollution may be reduced, the more relevant concern is whether animal wastes (manure and urine) are dispersed widely or concentrated (34). On large feed-lot farms, located primarily in the West and South, most feed is not grown on site and animal wastes are collected and stored. Such operations may represent point-sources of surface and groundwater contamination. On diversified farms located in the Upper Midwest and Northeast most feed is grown on site; animals have access to pasture, and wastes are left in pasture fields and/or recycled onto the fields. Some argue that diversified farms are less polluting than confined operations because wastes are spread over a more extensive area. A concern exists that bST will provide the economic incentive to create more confined operations and thereby increase pollution of ground and surface water.

These concerns are questionable. Diversified pasture operations are potential nonpoint sources of pollution in ground and surface water. If not properly managed, they could be significant sources of pollution. By the same token, handling practices and environmental regulations can minimize the threat of pollution from confined operations. Effective in-use handling practices include: 1) flush, lagoon irrigation systems; and 2) mechanical scrapers, storage pit, and tank wagon transport systems. In some areas, there is also a market for wastes for use as fertilizer, feed stuff, or fuel. In addition, the U.S. Environmental Protection Agency has provided regulations for confined livestock and poultry operations for surface-water protection and several States and local entities have stringent groundwater protection requirements for these operations (74). It is expected that these requirements will become quite common throughout the United States and eventually be applicable to most farming operations. Many small, diversified dairy operations will be at an economic disadvantage compared to larger operations in meeting these environmental requirements (66).

INSTITUTIONAL INVOLVEMENT IN bST RESEARCH

Research in the technology of bovine somatotropin has involved scientists and financial support from Federal agencies (NSF, NIH, USDA), State agricultural experiment stations, and private industry worldwide. This extensive collaboration has been of tremendous value in developing an understanding of the biology of somatotropin and of lactation. The number of publications on somatotropin to date is probably unprecedented for an animal technology not yet approved for commercial use. The bST literature is substantially larger than that for many dairy technologies in current use.

Some claim that extensive cooperation has totally compromised the quality and value of the research with bST. Kronfeld (44,45,46) has claimed that academic and government scientists are "indentured" and "biased" because of this association. Rifkin (63,64) and Epstein (23) have quoted Kronfeld and echoed these claims, repeatedly suggesting that the reporting of data has involved exclusion of sick cows and the suppression and deletion of adverse or negative results observed with bST supplementation of lactating cows. While these individuals offer no specific documentation of scientific fraud, such claims are not to be taken lightly. Current events demonstrate that research fraud is possible. However, a distinguishing feature of science is that research results are examined and repeated by others. This mechanism helps to identify inaccurate research. Published studies on bST have involved at least 10,000 dairy cows and results have been verified not only by numerous groups of U.S. scientists but by many other scientists throughout the world. The claims of Kronfeld, Rifkin, and Epstein imply a worldwide conspiracy involving at least 1,000 animal scientists in academia, government, and industry and hundreds of dairy farmers involved in the bST experiments. The possibility of such a conspiracy seems remote.

TIMING OF COMMERCIAL INTRODUCTION

Commercial use of bST requires approval by FDA and until this occurs, bST cannot be sold legally. Currently, bST is under review by the FDA and Federal law prohibits the agency from disclosing proprietary information on a drug under review. However, companies interested in bST have been relatively open about the fact that they are seeking approval and have published a considerable quantity of their own proprietary research. In addition, FDA has published an article using the companies' data to demonstrate the safety of bST for human consumption (38). This extensive disclosure of information on a drug under review is rare.

Each company wishing to market bST must prove that its product is effective (does what the company claims) and safe in order to secure FDA approval (67). The safety evaluation involves three areas: safety of the animal food products for humans; safety of the bST supplement to the target animals; and safety of using bST to the environment. In addition, each company must prove to the FDA that their manufacturing process can produce bST to consistent and acceptable quality standards.

In 1984, the FDA had sufficient scientific information from extensive published literature and then-unpublished studies (38,67) to make the determination that the milk and meat from bST-supplemented cows were safe for human consumption. Specific conclusions were:

1. bST is a protein that is digested enzymatically like any food protein when consumed orally.
2. bST has no biological activity in humans even if injected.
3. A trace level of bST naturally occurs in milk and meat but this level is not appreciably altered in cows receiving bST supplement.
4. The overall composition of milk is not altered due to bST treatment. The minor changes that can occur in the first few weeks of treatment due to shifts in nutrient balance are temporary and well within the normal variation encountered over the course of a lactation.

Thus, animal products were allowed to be marketed for the remainder of the investigational period.

In all other countries where bST is under review, the appropriate regulatory agencies have also completed the human safety evaluations and without exception, allow the milk to be used for human consumption. By 1990, a few countries completed all facets of their review and registered bST for commercial use by one or more companies (Soviet Union, Czechoslovakia, Bulgaria, Mexico, Brazil, and South Africa). In March 1991, the Committee for Veterinary Medicinal Products of the Commission of the European Communities released a favorable opinion on the application by one company for the marketing of bST.

PRODUCT LABELING

Some States are seriously considering mandatory labeling of all food products derived from milk of cows supplemented with bST. The basis for labeling seems to be a concern about the safety of the products for human consumption. At least two considerations need to be addressed.

First is the scientific merit or basis for labeling. If there is a valid safety concern then the food should not be marketed for human consumption. Labeling is not the appropriate method for handling a valid concern for consumer safety. If the regulatory system to evaluate food safety is inadequate, then the system should be changed. Labeling does not excuse the inadequacy. As just discussed, food safety concerns have been addressed and the conclusion reached is that food produced from bST-treated cows is safe for human consumption (38).

The second consideration is verification. An effective labeling program requires development and adoption of appropriate regulations and the establishment and funding of a system for implementation and verification. In the case of bST, there is no known test or technology that could be used to distinguish milk from bST-supplemented cows (38, 67). Indeed, no change in milk composition as a result of bST supplementation was found in human safety evaluations by FDA or analogous agencies in other countries.

CONCLUSIONS

OTA concludes that recombinant bovine somatotropin has no known adverse health effects on the cows receiving bST supplements or on humans drinking milk or consuming milk products from these cows. Recombinant bovine somatotropin is the first major biotechnology developed for agriculture. It will have potentially significant impacts on the dairy industry, based mainly on the fact that it can produce an average gain in milk per cow of 12 percent per year. However, this technology is not magic. It is distinguished only by the unprecedented magnitude of the productivity gains it yields. For example, the gain in productive efficiency obtained with bST supplementation would take 10 to 20 years to achieve using a combination of artificial insemination (using superior sires) and embryo transfer techniques (see table 3-3). Only the eradication of mastitis could increase milk yield per cow and productive efficiency as much as or more than the use of bST (6).

Table 3-3—Comparison of Theoretical Gains in Milk Yield Per Cow for Different Dairy Technologies

Technology	Theoretical annual gain in milk per cow[a]
Artificial insemination (AI)	100 kg[b]
AI plus sexed semen	115 kg[b]
AI plus embryo transfer	135 kg[b]
Bovine somatotropin	>1,000 kg[c]

[a] Actual observed gain would average less because of variation in quality of management and other factors. For example, observed gain from using artificial insemination and superior sires is approximately 50 percent of the theoretical gain.

[b] From Van Vleck (76). Gain would be cumulative for successive generations so long as variation exists in the population.

[c] From Bauman et al. (9)

SOURCES: L.D. Van Vleck, "Potential Genetic Impact of Artificial Insemination, Sex Selection, Embryo Transfer, Cloning and Selfing in Dairy Cattle," *in: New Technologies in Animal Breeding*, B.G. Brackett, G.E. Seidel, Jr., and S.M. Seidel (eds.) (New York, NY: Academic Press, Inc., 1981), pp. 221-241; D.E. Bauman, P.J. Eppard, M.J. DeGeeter, and G.M. Lanza, "Response of High Producing Cows to Long-Term Treatment With Pituitary—and Recombinant—Somatotropin," *J. Dairy Science*, 68:1352-1362, 1985.

For bST to be effective, dairy farmers must be expert managers. Poorly managed farms, where animals are stressed, underfed, and/or sick, will have negligible milk response to bST. In this respect, the bST-supplemented cow presents the same challenges as any high producing cow—the ultimate gains to be captured depend not on the technology per se, but on the management skills of its adopters.

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Chapter 4

Emerging Technologies in the Dairy Industry

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Chapter 4

Emerging Technologies in the Dairy Industry

Bovine somatotropin (bST) is the first major biotechnology product developed for the dairy industry. This product has been controversial and has raised many scientific and socioeconomic questions. BST, however, is not the only new technology that will affect the dairy industry. Advances in animal reproduction, animal health, and food processing are occurring, and many of the new technologies being developed use highly sophisticated and complex biotechnology methods. By comparison, the biotechnology methods used to produce bST are actually rather rudimentary; potentially some of these new technologies could make bST obsolete. These new technologies will increase the level of management skills needed to use them effectively; new information technologies will aid the decision-making process. Several conclusions can be drawn concerning the development of these new technologies:

- The dairy industry is on the verge of a technological revolution. Biotechnology methods that are more advanced than those used to produce bST are currently under development. The impact of these technologies, in conjunction with new information technologies in the not too distant future may rival that of bST. Assessment and analysis, similar to that of bST may be warranted for many of these technologies.
- The field of animal reproduction is advancing rapidly. Researchers have significantly improved their understanding of egg development in the ovary, how to stimulate the release of numerous eggs at once, and how to achieve fertilization and development of eggs outside of the cow. Embryos can be frozen for later use. Both embryos and sperm can be sexed. It is also possible to create multiple copies of an embryo, each of which can be transplanted into a cow whose reproductive cycle has been adjusted to be able to accept the embryo and carry it to term. These new technologies make it possible to improve herd quality more rapidly than can be achieved using traditional breeding methods.
- It is now possible to create transgenic[1] cattle, however, the techniques currently used are inefficient and require the use of thousands of eggs to produce just one transgenic animal. These inefficiencies make it too expensive to commercially produce and market transgenic livestock. However, scientific breakthroughs are leading to the development of technologies that will improve the efficiency of transgenic animal production and substantially lower the cost of doing so. Transgenic livestock may become commercially available in small numbers by the end of the decade.
- BST potentially could be supplanted by the development of transgenic cattle. Dairy cows can be developed to produce higher levels of bST so that daily injections or timed release formulations are no longer needed. Alternatively, genes that code for chemicals that suppress bST production can be altered in the cow such that a cow's normal bST production will increase.
- New biotechnology products are also being developed to improve animal health. Products include new vaccines and diagnostic kits, as well as compounds that enhance an animal's ability to fight disease.
- Not only are new biotechnology products being developed for use in livestock production, but they are also being developed for use in food processing. New products will improve the production of milk products such as cheese and yogurt. They can also be used to detect milk contaminants.
- Effective use of these new technologies will place a premium on management skill. New information technologies are being developed to aid farm management. These new technologies can incorporate individual farm data, with pertinent information from national databases, into computer programs that will aid farmers in the decisionmaking process.

This chapter describes information systems, and biotechnology methods and products that have been developed, or are expected to be developed for use in the dairy industry in the decade of the 1990s. Many of these technologies are highly sophisticated, cutting-edge technologies, and as such have not been extensively discussed in the lay literature. However, it is important that the potential of these technologies be understood. Given the nature of these new technologies, the following descriptions are, by necessity, somewhat technical.

---

[1] Animals whose hereditary DNA has been augmented by the addition of DNA from a source other than parental germplasm using recombinant DNA techniques.

BIOTECHNOLOGY AND THE DAIRY INDUSTRY

The term biotechnology refers to a wide array of techniques that use "living organisms (or parts of organisms) to make or modify products, to improve plants or animals, or to develop microorganisms for specific uses" (46). Under this broad definition, biotechnology includes many long-practiced dairy technologies such as animal breeding and cheese-making. New biotechnologies include recombinant DNA techniques, cell culture, and monoclonal antibody (hybridoma) methods (see box 4-A). The application of these new methods to the dairy industry has already generated a number of products for improving milk production, animal health, and food processing, and will continue to do so. Products now emerging range from rapid diagnostic tests for contaminants in dairy products to cows genetically engineered to produce high-value pharmaceuticals.

Reproductive Technologies and Transgenic Animals

Animal scientists generally agree that the most important cause of economic loss in the animal industries results from reproductive inefficiency

Box 4-A—Definitions of Commonly Used Terms

Antibody: Proteins produced by specific white blood cells (i.e., B lymphocytes) that bind specifically to foreign antigens in the body.

Antigen: Any substance that elicits a defensive (immune) response.

Cell culture: The growth and maintenance of cells derived from multicellular organisms under controlled laboratory conditions.

Chromosome: A thread-like structure composed primarily of DNA, that carries the genes which convey hereditary characteristics; in mammals chromosomes are contained in the nucleus and the X chromosome conveys female characteristics and the Y chromosome the male characteristics.

DNA (deoxyribonucleic acid): The molecule that is the repository of genetic information in all organisms (with the exception of a small number of viruses in which the hereditary material is ribonucleic acid-RNA).

Estrus: The period during which a female mammal is receptive to sexual activity.

Estrous cycle: The period of time needed for the reproductive cycle that includes egg maturation and ovulation in the ovary and preparation of the uterus to receive fertilized eggs. This cycle is under hormonal control and extends from the beginning of one period of estrus to the beginning of the next.

Hybridoma: A new cell resulting from the fusion of a particular type of immortal tumor cell line, a myeloma, with an antibody-producing B lymphocyte. Cultures of such cells are capable of continuous growth and specific antibody production

In vivo: Within the living organism.

In vitro: Outside the living organism and in an artificial environment, e.g., test tube.

Monoclonal antibodies: Identical antibodies that recognize a single, specific antigen and are produced by a clone of specialized cells.

Recombinant DNA: A broad range of techniques involving the manipulation of the genetic material of organisms; term is often used synonymously with genetic engineering; term also used to describe a DNA molecule constructed by genetic engineering techniques composed of DNA from different individuals or species.

Transgenic animals: Animals whose hereditary DNA has been augmented by the addition of DNA from a source other than parental germplasm using recombinant DNA techniques.

Uteri: The plural for uterus—the organ of the female mammal for containing and nourishing the young during development prior to birth.

SOURCE: Office of Technology Assessment, 1991.

(i.e., low conception rates and embryo mortality). The field of animal reproduction is currently undergoing a scientific revolution. In the 1986 report *Technology, Public Policy, and the Changing Structure of American Agriculture*, OTA predicted that, beginning about the year 2000, eggs matured and fertilized in vitro and transplanted to a recipient animal (artificial inembryonation) would in part, replace natural and artificial insemination in the animal breeding system, and embryos altered by recombinant DNA techniques (transgenics) would be commercially available. In fact, embryos produced by new reproductive methods are currently being marketed, although at present no transgenic embryos are commercially available. However, significant new advances are occurring, and the direction and timetable of developments will almost certainly be affected. This section focuses on recent advances in reproduction and recombinant DNA techniques and their application to the dairy industry during the decade of the 1990s.

It is now possible to select genetically superior females and induce them to shed large numbers of eggs (superovulation) that can be matured in vitro and fertilized with sperm from males selected for their desirable traits. The resulting embryos can be sexed, split to make duplicate copies, and stored frozen until needed. An embryo can then be transferred by nonsurgical techniques into the uterus of a recipient animal whose estrous cycle has been synchronized with the stage of development of the embryo. These new reproductive technologies can, and are being used to improve the quality of livestock herds more rapidly than could be achieved with traditional breeding, although currently many of these technologies are still relatively inefficient.

The ultimate goal of many workers in the field of animal biotechnology, however, is to produce animals whose hereditary DNA has been augmented by the addition of DNA from a source other than parental germplasm, using recombinant DNA techniques (transgenic animals) (47). Transgenic animals can be created that possess traits of economic importance including improved disease resistance, growth, lactation, or reproduction.

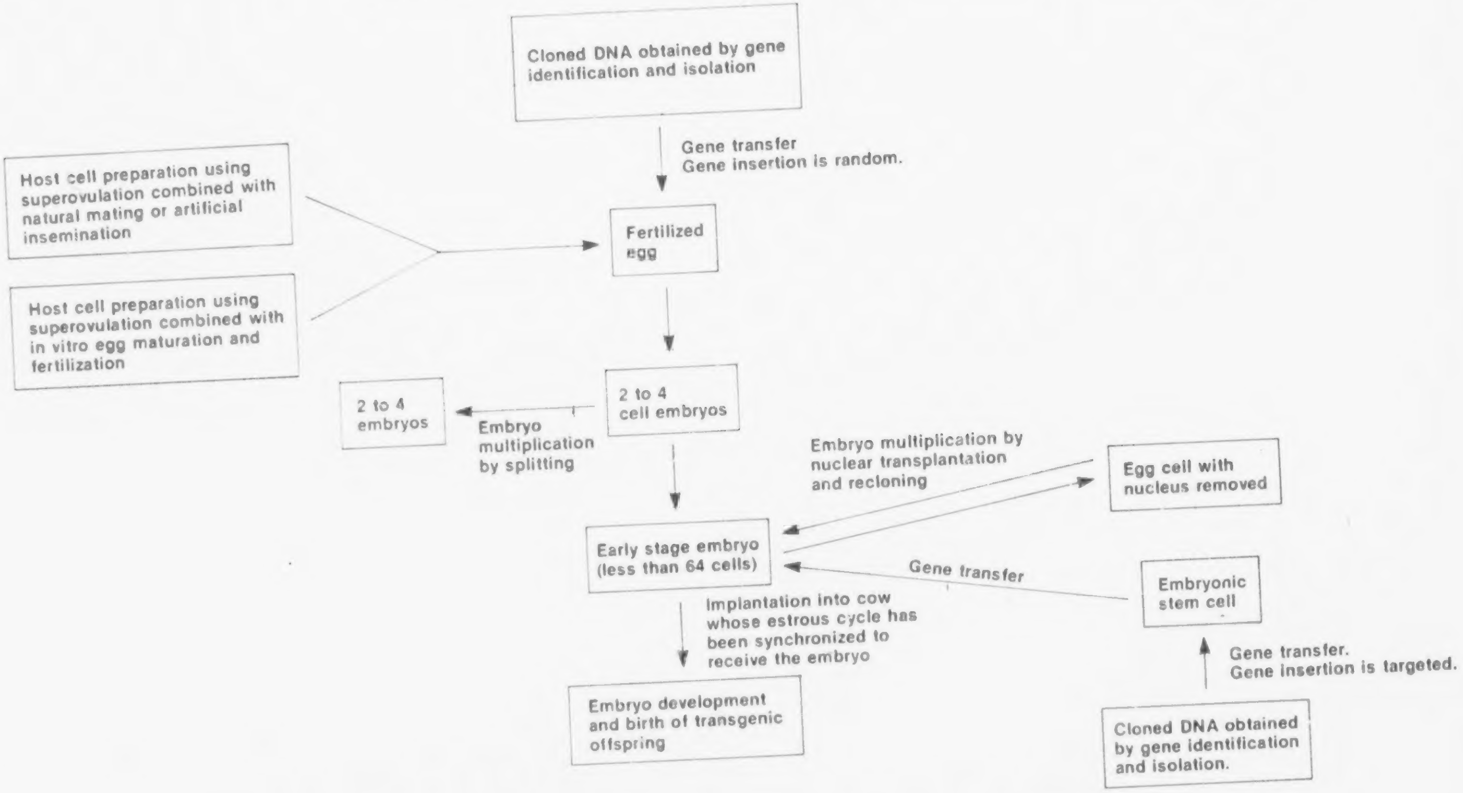
Transgenic livestock may also prove to be effective factories for the production of high-value pharmaceuticals, a development particularly pertinent for the dairy industry (9). Genes that code for animal proteins (e.g., tissue plasminogen activator-TPA) can be linked to regulatory sequences that direct high levels of gene expression in the mammary gland. This enhanced expression results in increased secretion of the desired animal protein into the milk of lactating females. This protein could then be extracted and purified from the milk. Transgenic cows producing pharmaceuticals have not yet been reported, but these animals are under development in a number of public and private laboratories. High levels of milk production coupled with the ease of milk collection may make this production method more cost effective than the cell culture systems currently used in the production of certain pharmaceutical proteins.

The production of transgenic animals is inextricably linked to development of new reproductive technologies. It is impossible to produce animals containing foreign DNA in their germlines without first manipulating the embryo and transferring it to a recipient animal. New reproductive technologies such as superovulation, in vitro egg maturation and fertilization, nuclear transplantation, and embryo sexing can be used to upgrade livestock herds. However, when they are combined with recombinant DNA technologies (the identification, isolation, and transfer of selected genes), they provide opportunities to efficiently and cost effectively produce transgenic animals, and to rapidly improve livestock quality (see figure 4-1). Therefore, advances in reproductive technologies will be discussed within the context of their applicability to the production of transgenic animals, recognizing that they are in their own right powerful tools for livestock improvements.

Steps in the Development of Transgenic Animals

The production of transgenic animals is a complex process, and involves four major steps. First, the desired gene must be identified, isolated, and prepared for insertion into a fertilized egg. Second, the host cell must be obtained and prepared for gene insertion. In livestock, the host cells used are generally fertilized eggs or early stage embryos. Third, the desired gene must be transferred to the host cell. And fourth, the resulting recombinant embryo is duplicated, and the resulting multiple embryos are transplanted into recipient cows that have had their estrous cycles synchronized to receive the embryo. This duplication process allows for the production of multiple offspring of genetically superior animals. Advances in each stage, discussed

Figure 4-1—Reproductive Technologies Used To Produce Transgenic Animals


Cloned DNA obtained by gene identification and isolation
Gene transfer
Gene insertion is random.
Host cell preparation using superovulation combined with natural mating or artificial insemination
Host cell preparation using superovulation combined with in vitro egg maturation and fertilization
Fertilized egg
2 to 4 cell embryos
2 to 4 embryos
Embryo multiplication by splitting
Embryo multiplication by nuclear transplantation and recloning
Egg cell with nucleus removed
Early stage embryo (less than 64 cells)
Gene transfer
Embryonic stem cell
Gene transfer.
Gene insertion is targeted.
Cloned DNA obtained by gene identification and isolation.
Implantation into cow whose estrous cycle has been synchronized to receive the embryo
Embryo development and birth of transgenic offspring

SOURCE: Office of Technology Assessment, adapted from J.P. Simons and R.B. Land, "Transgenic Livestock," *J. Reprcd. Fert. Suppl.* 34:237-250, 1987.

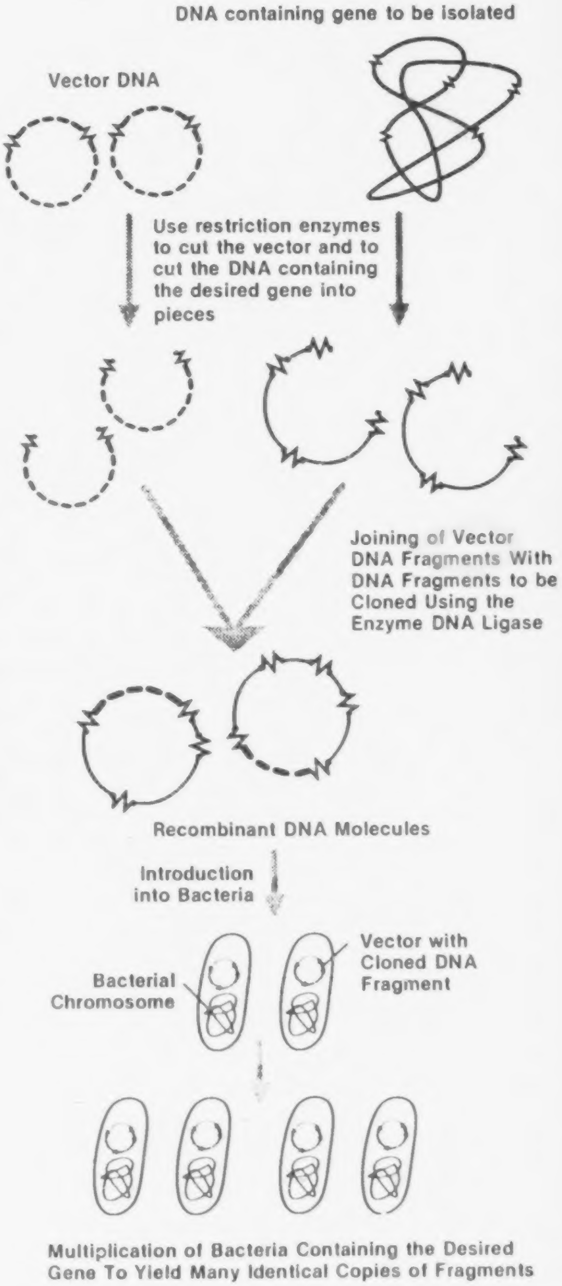
below, are improving the efficiency of transgenic animal production.

Step 1: Gene Identification and Isolation—Before a foreign gene can be transferred into the genome of a host cell to create a transgenic organism, the gene must first be identified and purified. This is done by a process called cloning. The tools used to clone DNA include special enzymes that cut and paste DNA, nucleic acid fragments that can be used to identify specific DNA sequences (probes), vehicles used to carry a foreign gene into a host cell (vectors), and host cells that can be used to produce multiple copies of the gene. The host cells used to multiply gene numbers are usually bacteria. The vectors most commonly used are bacterial plasmids, circular pieces of DNA that are easily inserted into bacterial cells and are capable of independent replication inside the bacteria (see figure 4-2).

Isolating a single gene is complicated by the fact that a DNA sample may contain millions of genes. Researchers must be able to separate the one gene of interest from all of the other genes. To do this, the DNA sample containing the desired gene is cut into pieces with special enzymes (restriction endonucleases). The bacterial plasmid (vector) is also cut with the same enzyme. The pieces of sample DNA, including any pieces carrying the desired gene, are inserted into vectors and the loose ends of the sample DNA and bacterial plasmid are pasted together (using the enzyme DNA ligase). These recombinant DNA vectors are then inserted into bacterial cells, and the bacterial cells are grown. At this point the bacterial cells containing the plasmid carrying the desired gene must be identified and isolated from the rest. This is done by using a probe, a nucleic acid sequence that recognizes the desired gene. Once the bacterial cells containing the desired gene are found, those cells can be grown in isolation to produce millions of copies of the vector containing the desired gene. The vector can be removed from the bacterial cells, and the desired gene isolated. This procedure can yield millions of copies of the desired gene that are free from contamination by other genes (48).

The purified gene can then be combined with appropriate regulatory genes that control the circumstances under which the gene is turned on and off. The purified gene and its regulatory sequences can be inserted into a vector such as a virus, for example,

Figure 4-2—Identification and Isolation of Desired Gene


DNA containing gene to be isolated
Vector DNA
Use restriction enzymes to cut the vector and to cut the DNA containing the desired gene into pieces
Joining of Vector DNA Fragments With DNA Fragments to be Cloned Using the Enzyme DNA Ligase
Recombinant DNA Molecules
Introduction into Bacteria
Bacterial Chromosome
Vector with Cloned DNA Fragment
Multiplication of Bacteria Containing the Desired Gene To Yield Many Identical Copies of Fragments

SOURCE: Office of Technology Assessment, 1989.

that will carry these genes into an animal cell and incorporate them into the genome (see gene transfer technologies). The tools used to purify genes are well developed. The major challenge is determining which genes are to be purified.

Step 2: Preparation of the Host Cell—Because current technologies used to transfer a gene into a host cell are inefficient, to get just one transgenic animal requires the use of thousands of fertilized eggs. To attain such large numbers of embryos, cows must be induced to shed large numbers of eggs (superovulation) that can be matured and fertilized in vitro. Increased understanding of the control of ovarian functions is improving the efficiency of obtaining sufficient numbers of fertilized eggs.

Control of Ovarian Functions—The lack of highly repeatable, efficient means for inducing superovulation is a major constraint. Induction of superovulation requires detailed knowledge of the hormonal factors that control the development of the egg in the ovary. The process of egg development has been subjected to intense investigation and a number of significant advances have been made during the past 5 years. Studies that have explored the basic mechanisms controlling egg growth and maturation, and corpus luteum[2] function, have paved the way for developing even more precise methods for regulating the estrous cycle, producing superovulation, and reducing the heavy losses due to early embryo deaths.

Perhaps the most important development in ovarian physiology in recent years is the discovery of the ovarian hormone inhibin, which decreases the ovulation rate.[3] Some breeds of animals with exceptionally high ovulation rates, such as the Booroola strain of Merino sheep in Australia, are known to have low levels of circulating inhibin (4). Cattle immunized against inhibin have lower circulating levels in their blood and show increased ovulation rates (21). The genes controlling inhibin production have been cloned and the potential exists for producing transgenic animals in which these genes are repressed or deleted.

Progress has also been made in understanding the control mechanisms that regulate corpus luteum function and its production of progesterone, a hormone that regulates the length of the estrous cycle and helps maintain pregnancy. This understanding paves the way for development of more precise methods for regulating the estrous cycle, which is needed to synchronize surrogate mothers, and for producing superovulation. Superovulation treatments are initiated when the ovaries are under the influence of progesterone. Currently, superovulation treatments use highly purified hormones produced by recombinant DNA technology and produce, on average, about 10 viable eggs per treatment (compared to the 1 egg a cow normally produces per ovulation) (21). As the new knowledge of the factors controlling egg development and corpus luteum function is applied, the number of viable embryos produced by each superovulation treatment is expected to increase.

In Vitro Maturation and Fertilization of Eggs—In vitro maturation and fertilization of eggs recovered by superovulation provides a means of overcoming the problem of livestock reproductive inefficiency. Normally, a bovine ovary contains about 50,000 immature eggs at puberty, however, on average only 3 to 4 of these eggs will result in the births of live calves during the animal's lifetime. Using present superovulation methods, about 10 viable eggs can be harvested from the ovaries of 1 treated cow and about half of these develop into embryos suitable for transfer. Improved superovulation technology may lead to the recovery of more eggs suitable for in vitro fertilization such that the number of live births resulting from a superior animal could be quite high.

In vitro fertilization occurs only when a capacitated sperm (i.e., a sperm specially prepared to penetrate the egg cell membrane) encounters an egg at an optimal maturation state. Great progress has been made in understanding the factors involved in egg maturation and sperm capacitation in livestock. As a result, offspring have been produced in cattle, swine, sheep, and goats following in vitro fertilization (16) and attempts to market embryos produced with these techniques are already underway.

Step 3: Gene Transfer Technologies—Achieving the goal of transgenic animal production requires the development of efficient and cost effective ways to transfer the selected genes to an embryo. Mice were the first transgenic mammals created (see figure 4-3), and were produced by microinjecting

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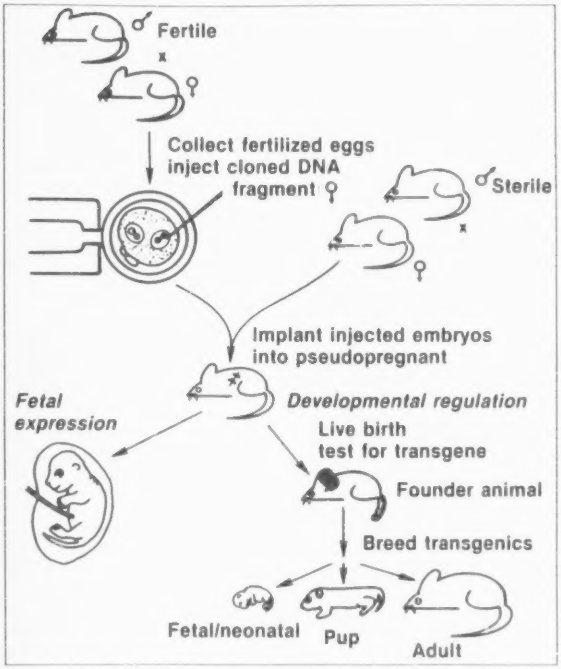
[2] The corpus luteum is a temporary endocrine organ that is produced at the site of ovulation during each estrous cycle.

[3] Inhibin decreases ovulation rates by suppressing the secretion of follicle stimulating hormone (FSH), a hormone produced by the pituitary gland.

Figure 4-3—Process of Producing a Transgenic Mouse



SOURCE: Sally A. Camper, Fox Chase Cancer Center.

cloned DNA into a fertilized egg[4] (32). Alternatively, viral vectors can be used to transfer cloned DNA into a host embryo (14). The embryo is then transferred to a recipient animal whose estrous cycle has been synchronized to accept and carry to term, the developing embryo.

A number of transgenic cattle, pigs, sheep, and chickens have been produced by these techniques, however, they are of limited use because of the high cost and low efficiency of microinjection techniques, and the absence of appropriate viral vectors for use in most livestock species. Additionally, DNA transferred by these methods is inserted randomly into the host genome, resulting in a lack of control of the gene transfer process (20).

Because of the deficiencies encountered with using viral vectors or microinjection methods to create transgenic livestock, alternative methods are being sought. A promising new method for generating transgenic animals has recently been developed in mice and may be applicable to other mammals. This new technique uses stem cells derived from an embryo. Stem cells are cells that are normally undifferentiated, that is, they do not become specialized tissue cells such as muscle, brain, liver cells, etc. However, stem cells retain their ability to become specialized cells when given the proper stimuli (i.e., they are pluripotent).[5] These stem cells can be used as vectors to introduce selected genes into a host embryo. This method has several significant advantages over microinjection methods, the most profound of which is that for the first time, it is possible to insert DNA at specific, predetermined sites within the genome of the stem cells (8). Targeted insertion is possible because stem cells have an intrinsic ability to recombine similar (homologous) DNA sequences, which results in the replacement of the endogenous gene with the desired gene.

Stem cells must first be isolated (see figure 4-4). An early stage embryo is cultured on a thin layer of specially prepared cells. The proliferating embryo cells are recultured until individual stems cells can be isolated. These individual stem cells can then be cultured indefinitely. At this stage, DNA sequences containing desired genes can be inserted into the stem cells.[6] A genetically transformed stem cell is then microinjected into an immature embryo to produce a chimera, an organism that contains cells from more than one source. If the stem cells are incorporated into the germ lines of these chimeric animals, then these animals can be interbred to obtain offspring that are homozygous for the desired trait (8).

Application of the gene targeting method makes possible a broad range of phenotypes for transgenic animals that could not be produced economically using direct microinjection or viral vectors. Targeted gene insertion allows endogenous genes to be

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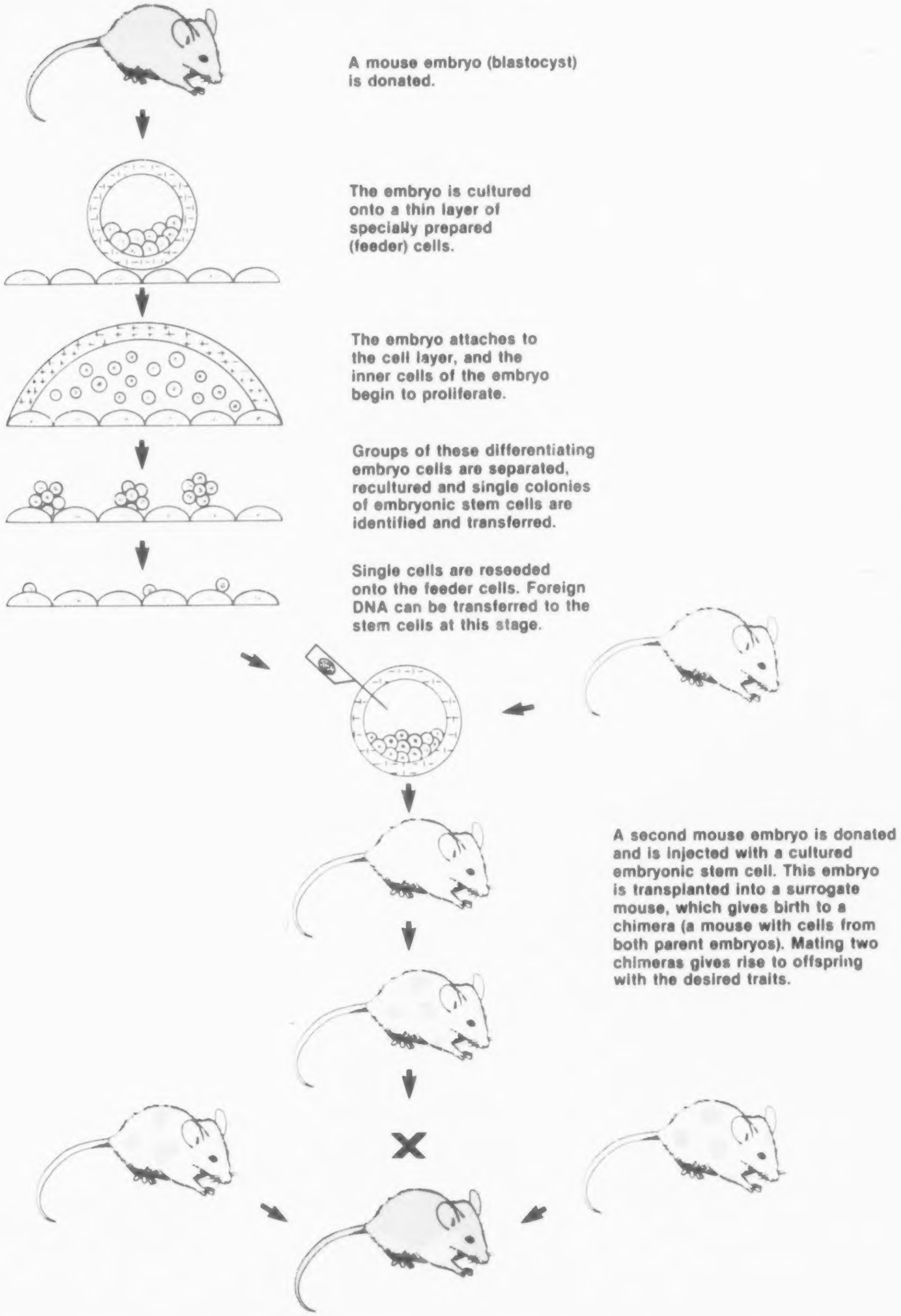
[4] Specifically, the DNA is injected into the male pronucleus of the fertilized egg. The pronucleii are the egg and sperm nucleii present after the sperm penetrates the egg membrane.

[5] Pluripotency help make stem cells attractive vectors of DNA transfer. While in tissue culture, DNA can easily be inserted into stem cells. When stem cells are injected into an early stage embryo, the conditions for tissue specialization are present, and stem cells undergo the normal tissue development that occurs as the embryo develops during pregnancy. Thus, using stem cells provides an efficient means to transfer DNA.

[6] Methods used include viral infection and use of an electric pulse to make cell membranes leaky (electroporation).

Figure 4-4—Gene Transfer Using Embryo Stem Cell Culture[a]



A mouse embryo (blastocyst) is donated.

The embryo is cultured onto a thin layer of specially prepared (feeder) cells.

The embryo attaches to the cell layer, and the inner cells of the embryo begin to proliferate.

Groups of these differentiating embryo cells are separated, recultured and single colonies of embryonic stem cells are identified and transferred.

Single cells are reseeded onto the feeder cells. Foreign DNA can be transferred to the stem cells at this stage.

A second mouse embryo is donated and is injected with a cultured embryonic stem cell. This embryo is transplanted into a surrogate mouse, which gives birth to a chimera (a mouse with cells from both parent embryos). Mating two chimeras gives rise to offspring with the desired traits.

[a] This technique is currently developed only for mice and hamsters and possibly rabbits and swine. It is not yet developed for cattle.

SOURCE: M.R. Capecchi, "The New Mouse Genetics: Altering the Genome by Gene Targeting," *Trends in Genetics* 5:70-76, 1989.

inactivated or replaced with modified forms of the gene, such as one that is expressed at a higher level, has a new pattern of tissue specific expression, or has a modified biological activity.

Perhaps the most significant advantage of the gene targeting approach is that it allows for endogenous genes to be effectively removed. Genes can be inactivated by targeting insertion into an essential region of the gene. This fact is of particular interest to the livestock industry, because inactivation of genes that have inhibitory physiological effects is likely to result in improvement in a number of productive traits. For example, bovine somatostatin is a hormone that inhibits bovine somatotropin production; inactivation of this gene would result in increased endogenous somatotropin secretion and, presumably increased milk production and more efficient growth. If successful, this technology would supplant the need to administer bST exogenously to increase milk production (see ch. 3). The genes controlling the production of inhibin, the ovarian hormone that reduces ovulation rate, is yet another example. The ability to inactivate genes also provides a powerful research tool that allows scientists to study the function of genes in vivo. The absence of a method to produce embryo stem cell lines from cattle is currently preventing the use of the gene targeting approach in the dairy industry,[7] however, a number of laboratories are trying to develop this technology.

Step 4: Embryo Multiplication—The production of multiple copies of a genetically engineered embryo is the final step in the development of transgenic animals. Efficient and inexpensive multiplication technologies are tremendously important for improving the efficient development of transgenic animals. Multiple copies of a mammalian embryo were first produced by physically splitting an early embryo into halves, giving rise to identical twins (21). If the embryo is divided more than twice, however, few offspring survive. Thus, no more than four identical animals can be produced by splitting and generally only two embryos are produced by this method. This procedure is already used in the cattle embryo transfer industry, nearly doubling the number of offspring produced.

A more efficient and promising method of producing multiple copies of an embryo is by a technique called nuclear transplantation. Basically, the procedure involves the transfer of a nucleus from a donor embryo into an immature egg cell whose own nucleus has been removed. The recipient egg cell is activated by exposure to an electric pulse, allowed to develop into a multicelled embryo, and then used as a donor in subsequent nuclear transplantations to generate multiple clones. This procedure (outlined in figure 4-5) has been used successfully with cattle (7,35), sheep (42,49), and swine (36). Using this technique, hundreds of pregnancies have already been produced in cattle and recloning has been performed successfully resulting in as many as eight calves from one embryo (28).

The value of this technique to the dairy industry is enhanced by the ability to successfully transfer nuclei from frozen embryos into eggs whose nuclei have been removed. Conception rates obtained after transfer of embryos produced by nuclear transplantation are variable, but rates as high as 50 percent have been obtained. However, embryo losses after transfer are higher than normal, resulting in actual pregnancy rates ranging from 15 to 33 percent (7). Combining the techniques of in vitro fertilization, embryo cloning, and artificial estrous cycle regulation will likely result in major changes in dairy cattle breeding and in the rates of genetic improvement.

While significant advances in transgenic animal production have been made, it is unlikely that transgenic animals will be commercially available before the end of the 1990s at the earliest. The ability to produce transgenic cattle possessing traits of economic value is currently limited by the absence of embryo stem cell technology and the lack of knowledge about the relationship between the expression of a specific gene and the physiological consequences. While the techniques for isolating and sequencing bovine genes are now straightforward, understanding of the functions of the genes has lagged. Analysis of gene function is complicated by the fact that many traits are controlled by multiple genes. Thus, manipulation of such traits will require detailed understanding of these genes and their interactions. Ultimately identifying and understanding the physiology of the major genes controlling lactation, reproduction, and disease and stress resistance in dairy cattle is needed. An active genome mapping program could help enhance these developments.

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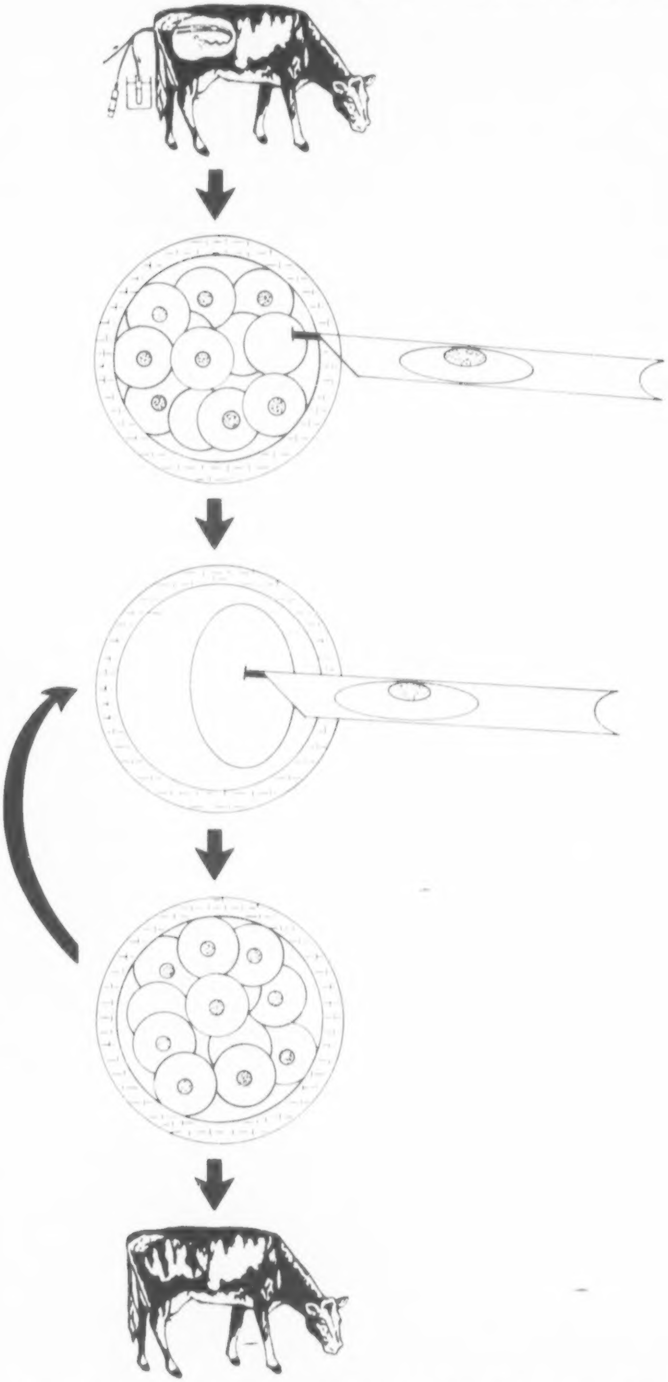
[7] The stem cell technology has been developed for mice, hamsters, and swine.

Figure 4-5—Nuclear Transplantation



An embryo is nonsurgically removed from a donor cow or is produced by in vitro fertilization.

Individual embryo cells are removed.

Each embryo cell is injected into a specially prepared egg cell that has had its nucleus removed. An electric pulse is administered to cause fusion.

Each egg cell is grown to a multicell embryo at which point the cloning procedure can be repeated

or

the embryo can be transplanted to a cow that eventually gives birth.

SOURCE: Office of Technology Assessment, adapted from R.S. Prather and N.L. First, "Cloning Embryos by Nuclear Transfer," *Genetic Engineering of Animals*, W. Hansel and B.J. Weir (eds.), *Journal of Reproduction and Fertility Ltd.*, Cambridge, UK, 1990, pp. 125-134.

Sexing of the Offspring

The availability of a technique to preselect the sex of the progeny is of great economic potential for the dairy industry where females are the major income producers and artificial insemination is already widely used. Until recently, none of the methods resulted in the degree of separation needed for commercial use. However, recent advances in the separation of the X and Y sperm, and sexing of the embryo have been made.

Separation of the X- and Y-Bearing Sperm—It has long been a goal of mammalian physiologists to develop a method for effectively separating X and Y chromosome-bearing sperm to control the sex of the offspring. Most sperm separation techniques are based on potential differences in the size and density of the two sperm types.[8] These methods, however, have met with limited success (41).

Development of cell sorting techniques based on the differences in sperm size and fluorescence of sperm DNA (flow cytometric measurements) has provided the first effective method to sort the sperm cells. Johnson et al. (24) recently reported successful separation of intact viable X and Y chromosome-bearing sperm using this method (see table 4-1). Although the difference in DNA contents of the X and Y chromosome-bearing sperm in rabbits amounts to only about 3 percent, 94 percent of the rabbits (does) inseminated with X-bearing sorted sperm produced females and 81 percent of the does inseminated with Y-bearing sorted sperm produced males. Commercial use of this process is limited, at present, by the number of sperm that can be sorted per hour and by increased embryo mortality observed in the embryos produced after insemination with the sorted sperm. Neither of these factors is thought to represent an insurmountable difficulty.

Embryo Sexing—The most accurate method for sexing embryos is to create a picture of the number, size, and shape of the chromosomes contained in the embryonic cells (karyotyping). However, this method requires removal of about half of the cells of early-stage embryos, which decreases embryo viability and limits the number of embryos that can be transferred. Another method uses antibodies[9] to detect proteins (antigens) unique to male embryos. This method is not damaging to the embryos and encouraging results have been obtained in one laboratory (2), however, the technique yields variable results and has not been widely adopted.

More recently, the sex of bovine embryos has been determined by using fragments of DNA that are contained only on Y chromosomes as a means of identifying the same DNA fragments in the embryo (6). Due to its chemical structure, a fragment of DNA will combine with a second DNA fragment that has a corresponding nucleic acid sequence. Therefore, a fragment of DNA that is specific to males can be used as a probe to identify male DNA fragments in the embryo. Combined with technologies that multiply the number of copies of the DNA fragments, this method determines the sex of the embryo using only a few cells. It is rapid (about 6 hrs) and extremely accurate, but may be overtaken by the rapidly developing technology, described above, for separating X and Y chromosome-bearing sperm.

Animal Health Technologies

Biotechnology is rapidly acquiring a prominent place in veterinary medical research. Initially applied to vaccine development, it most recently has contributed to efforts to develop diagnostic procedures and to improve detoxification systems.

Vaccines

Vaccines are agents that stimulate an effective immune response but do not cause disease. Traditional methods of vaccine development involved killing or modifying the pathogenic organism to reduce the potential for disease while preserving its ability to induce an immune response. Recombinant vaccine development involves either deletion or inactivation of genes necessary for disease, or insertion of immunizing genes into nonpathogenic vectors.

Gene deletion technology has been successfully used to develop both viral and bacterial vaccines. A naturally occurring mutant of E. coli, for example, has been shown to provide protection against gram-negative bacterial infections in cattle and swine (15,18). Live Salmonella modified to prevent

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[8] Methods used are differential sedimentation techniques including differential velocity sedimentation, free-flow electrophoresis, and convection counter streaming galvanization.

[9] The antibodies are attached (labeled) to a fluorescent compound to allow for detection.

Table 4-1—Predicted and Actual Sex Ratios of Offspring After Intrauterine Insemination of Sorted X and Y Chromosome-Bearing Rabbit Sperm

	Number of does			Percentage and number of offspring					
				Predicted[a]		Actual[b]			
Treatment of sperm	Inseminated	Kindled	Total of young born	Males	Females	Males	(N)	Females	(N)
Sorted Y	16	5	21	81	19	81	(17)	19	(4)
Sorted X	14	3	16	14	86	6	(1)	94	(15)
Recombined X and Y	17	5	14	50	50	43	(6)	57	(8)
Total	47	13	51	—	—	47	(24)	53	(27)

[a] Represents the results of reanalysis for relative DNA content of aliquots of sorted X- and Y-bearing sperm populations.

[b] Represents actual births.

SOURCE: L.A. Johnson, J.P. Flook, and H.W. Hawk, "Sex Pre-Selection in Rabbits: Live Births From X and Y Sperm Separated by DNA and Cell Sorting," *Biol. Reprod.* 41:199-203, 1989.

reproduction in vivo have also proven to be effective vaccines for cattle (12).

The first gene deletion viral vaccine to be approved and released for commercial use was the pseudorabies virus vaccine for swine (26,30). Initially, a single gene deletion reduced the virulence of the virus. Since then, other genes have been deleted with a continuing reduction of virulence.

Vaccines can also be created by inserting into pathogens, genes that produce protective antigens that reduce the ability of the pathogen to cause disease.[10] Some of these vaccines, however, will have to be carefully tested because they have a slight potential to cause human infection (31). Others are in the early developmental stages (notably herpes virus vaccine and adenovirus vaccine).

Immunomodulators

Immunomodulators are chemical compounds that boost or accentuate immune response. Several such compounds (e.g., interleukins and interferons) have been identified in mammals, and the genes encoding some of these compounds have been isolated and cloned into bacteria (31). Mechanisms by which these regulatory proteins modulate immune response is now being investigated in domestic animals (1). Biotechnology is being used to identify and replicate these compounds so that their function can be investigated.[11]

Interleukin genes and genes for compounds that cause immune responses in animals (antigens) are being inserted together into viral or bacterial vaccines. This combination could possibly enhance the immune response of the animal and lead to increased protection against the antigen. The recombinant interleukins produced in bacteria or other expression vectors may also be used therapeutically to assist in overcoming certain infections.

Diagnostics

Safe, accurate, rapid, inexpensive, and easy-to-use diagnostic procedures are critical to the dairy industry at virtually all points in the production process. Examples of diagnostic tests include pregnancy tests and assays for pathogenic organisms. Many of the currently used diagnostic tests are costly, time consuming, and labor intensive, and some still require the use of animal assay systems. Monoclonal antibodies and nucleic acid hybridization probes can be used to produce simpler, easily automated, and highly sensitive and specific diagnostic procedures.

Antibodies are proteins produced by the body in response to foreign chemical substances. Monoclonal antibodies are produced by a cell line expressing only a single antibody type (see figure 4-6). They can be used to prevent disease,[12] and are the primary tools for biotechnology-based diagnostics. At least 15 different rapid diagnostic tests are on the market or will be soon. These tests are highly specific and most lend themselves to automation, potentially allowing their application in mass screening systems for disease surveillance and control. Some of the tests have been adapted to field use and can be used by veterinarians or producers. The rapid commercialization of these products is having a significant impact on animal health management and disease control.

Monoclonal antibodies are also being used in enzyme-linked-immunoabsorbent-assay (ELISA) systems to provide sensitive, quantitative blood assays (see table 4-2) of toxins, hormones, chemicals (e.g., pesticide and antibiotic residues), and a variety of antigens including microbial agents (19,29,34,38). Many of these tests are commercially available. In some instances monoclonal antibody diagnostics have been used to replace bioassays such as mouse inoculation tests.

"Nucleic acid hybridization" can also be used to diagnose the presence of microbes and parasites. Such assays rely on the bonding of a specific DNA or RNA segment to complementary RNA or DNA fragments in a test sample. Specific segments (probes) are available to detect viruses such as

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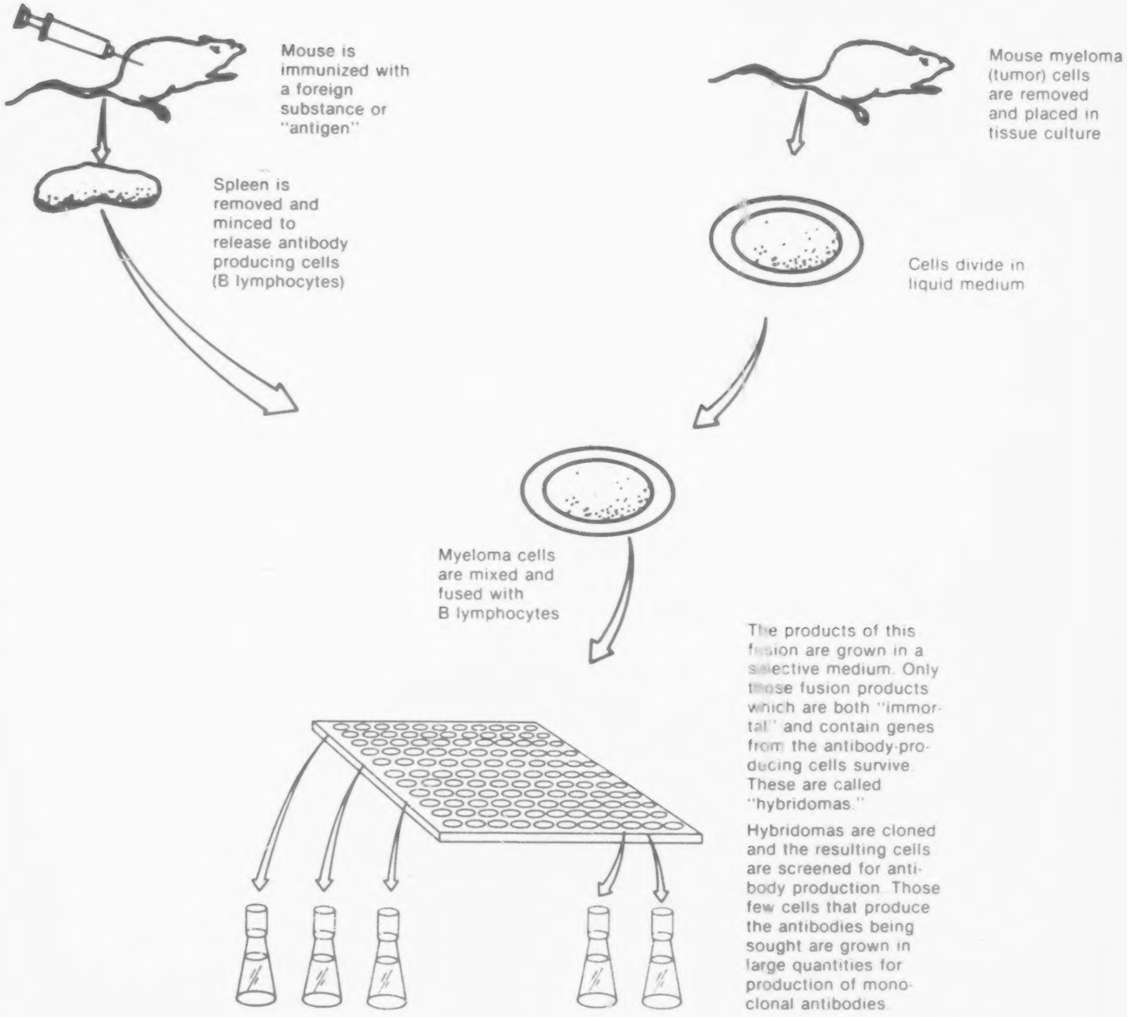
[10] The first veterinary recombinant viral vaccine was the vaccinia vectored vesicular stomatitis vaccine (27). This has been followed by the vaccinia vectored rabies and rinderpest vaccines (3,5,50).

[11] Cloned interleukin genes, such as bovine alpha, beta and gamma interferon, bovine interleukin-2 (IL-2) etc. have been studied both in vitro and in vivo.

[12] A commercial preparation of monoclonal antibodies directed to the K-99 pilus antigens of pathogenic E. coli, for example, prevents diarrhea in newborn calves (31).

Figure 4-6—Preparation of Monoclonal Antibodies


Mouse is immunized with a foreign substance or "antigen"
Spleen is removed and minced to release antibody producing cells (B lymphocytes)
Mouse myeloma (tumor) cells are removed and placed in tissue culture
Cells divide in liquid medium
Myeloma cells are mixed and fused with B lymphocytes
The products of this fusion are grown in a selective medium. Only those fusion products which are both "immortal" and contain genes from the antibody-producing cells survive. These are called "hybridomas."
Hybridomas are cloned and the resulting cells are screened for antibody production. Those few cells that produce the antibodies being sought are grown in large quantities for production of monoclonal antibodies.

SOURCE: Office of Technology Assessment, 1988.

bluetongue, bovine virus diarrhea, and foot and mouth disease as well as many parasites and bacterial diseases. The major limitation of this technique is the small amount of target nucleic acid present in some samples. Also, the most reliable methods use radioactively labeled probes, and require expensive equipment and trained technicians, thus precluding their use in the field. Alternative colorimetric techniques currently in development will replace the radioactively labeled probes and make the use of this technology more commercially attractive.

Table 4-2—Monoclonal Antibodies for Diagnostic Tests

E. coli K99 antigen
Pseudorabies virus antibody
Avian leukosis virus antigen
Equine infectious anemia antibody
Avian reovirus antibody
Bluetongue virus antibody
Bluetongue virus antigen
Brucella abortus antibody
Avian encephalomyelitis antibody
Bovine progesterone
Sulfa methazine in milk
Crytosporidium
Bovine leukemia virus
Bovine herpes virus
Aflatoxin B
Sulfamethazine—swine

SOURCE: B.I. Osburn, "Animal Health Technologies," commissioned background paper prepared for the Office of Technology Assessment, Washington, DC, 1990.

Food Applications

Dairy products will be among the first food products to be impacted by biotechnology. For example, during the next decade, the genetically engineered version of the enzyme rennet, recently approved by FDA for use in cheese manufacturing systems, will replace the enzyme preparation normally extracted from the forestomach of calves. Other enzymes, which are added to the curd to accelerate ripening, or to produce dairy products acceptable for digestion by lactose-intolerant individuals, will also be produced more economically by engineered microorganisms (22).

Dairy starter cultures are living microorganisms used for the production of fermented dairy products including cheese, yogurt, butter, buttermilk, and sour cream. They have been safely consumed by humans for centuries and serve as ideal hosts for the production of these natural foods. The metabolic properties of these organisms directly affect the properties of the food product including flavor and nutritional content. In order to improve various properties of food products, food microbiologists attempt to manipulate the traits of the microorganisms, primarily through mutation and selection. The cloning and gene transfer systems developed in the 1980s are being used to construct strains with improved metabolic properties more rapidly and precisely than is possible with traditional methods. The development in this decade of new strains with precise biochemical traits will have an impact on several aspects of dairy fermentation, including production economics, shelf-life, safety, nutritional content, consumer acceptance, and waste management (22).

Although much of the current work in new strain development has focused on the use of E. coli and other nonfood microorganisms, there are distinct advantages to engineering starter cultures for producing high-value foods. For example, construction of cultures resistant to attack by viral infection will impact processing costs by eliminating waste. Cloning of the genes responsible for ripening of aged cheeses will decrease storage costs by accelerating ripening. Production of natural preservatives such as nisin, effective in inhibiting foodborne pathogens and spoilage organisms, will help ensure the safety and extend the shelf-life of fermented dairy products. Cloning of the gene(s) responsible for enzymatic reduction of cholesterol or modification of the degree of saturation of milk fat will improve the nutritional quality of fermented dairy products. The ability to engineer strains capable of producing enhanced flavors or natural stabilizers will influence consumer acceptance of fermented dairy foods.

Engineered yeast strains capable of fermenting the lactose in whey to value-added products, such as vitamin C, biofuels such as ethanol and methanol, or pharmaceuticals, will facilitate management of this waste product. Whey protein could potentially be used to produce specialty chemicals with biotechnology.

Nucleic acid probes and monoclonal antibodies can be used to analyze raw materials, ingredients, and finished products for pathogenic organisms, bacterial or fungal toxins, chemical contaminants (i.e., pesticides, heavy metals), and biological contaminants (i.e., hormones, enzymes). Animal cell cultures may partially replace whole animal systems to test for acute toxicity. Biosensors may be used to monitor food processing, packaging, transportation, and storage (22).

KNOWLEDGE-BASED INFORMATION SYSTEMS

The economic vitality of an animal enterprise is dependent on expert managers who formulate, implement, and continually fine-tune relevant plans and goals in order to optimize resource use and output (10). However, producers may have difficulty evaluating the many interrelated factors that go into such planning (17). Even a relatively simple animal operation requires that complex decisions be made, based on simultaneous consideration of dynamically changing factors related to risk, efficiency, disease, milk production, gestation status, and weather. With technology changing so rapidly, it has become almost impossible for agricultural managers to balance all of the facets of milk production now under their control (45).

Many producers rely on consultants and experts to sift through the data and information needed for informed management decisions. In addition, computers have come to play a significant role in dairying, an industry that historically has used records to make management decisions. Initially, data resided in mainframe computers. This allowed for professional maintenance of the database, but the ultimate user-producer had limited access to that database.

Examples of database access via telecommunication systems include the Direct Access to Records by Telephone (DART) system, run by the Dairy Records Processing Center at Raleigh, North Carolina; and the Remote Management System (RMS) available through Northeast Dairy Herd Improvement (DHI). Although dairy records processing centers (DRPCs) like the one at Raleigh have not developed software for onfarm data calculation and information storage, the private sector has. Pollock and Fredericks (33), for example, offer a microcomputer-based diagnostic program with which producers can avoid the time, recurring costs, and problems of phone access to a distant mainframe.

As computer languages have evolved and microcomputers decreased in price and gained computing capacity, database accessibility has increased. Microcomputers provide for direct, rapid delivery of management data, as well as more efficient data handling and user interfaces. They have, accordingly, revolutionized production record-keeping, and made possible onsite data manipulation and farm-level processing of information (45).

Expert Systems and Other Computer-Based Decision Aids

Management decisions rest on a knowledge base consisting of two kinds of information: that which is widely shared and generally publicly available (domain information); and rules-of-thumb judgments and sometimes educated guesses (heuristics), which typically characterize human decisionmaking. Both kinds of information are fundamental to computer-based expert systems (11), the objective of which is to raise the performance of the average producer to the expert level (39). Expert systems effectively and rationally integrate numeric, judgmental or preferential, and uncertain information, all of which come into play in the biologically based, weather-influenced production systems that typify animal agriculture (23). Another promising new information technology is the management-information system, with which managers can test the outcome of various management alternatives. Decision-support systems also hold high promise of enabling managers to balance production inputs in a way that maximizes response (output).

Expert systems, knowledge-based systems, or decision-support systems offer the potential of bringing the consultant to the farm through the microcomputer. An expert system provides a flexible yet structured approach to many problems that Extension specialists now solve relatively routinely (43). Interest in these systems is beginning to emerge as a field of research and development in agriculture, reflecting both industry awareness and appreciation of new information-management technologies (13). With the widespread introduction of specialized development tools, expert system construction has accelerated (25,37). For example, development of expert systems was, until recently, restricted to expensive LISP (a computer language) processing machines and mainframe computers. Recent advances in hardware and software have made possible the development of reasonably sized expert systems on microcomputers. Newly released expert system shells have removed the necessity to program in LISP (44). While conventional computer programs manipulate data (11), expert systems manipulate knowledge and help determine which data are useful to the decisionmaker. They are not competitors but extensions to conventional computer programs.

Application of New Information Technology

Pressure for the management expertise offered by these new information technologies will grow in the 1990s as farms increase in size, new technologies emerge, prices fluctuate, and consumer concern about food safety and diet increases. Problem solving and successful adoption of new agricultural technologies like bST will be facilitated if the knowledge acquired from research and the expertise acquired in practice are combined and made readily available in easy-to-use forms.

Indeed, the possibility of fusing expert knowledge from different domains (extension, research, producer/managers) into a cohesive, accessible structure might be the most promising advantage of the new information technologies (11). This will allow management opportunities to be maximized, a wider group of individuals to be reached, and specialists to allocate more time to new areas of concern. Expert systems, for example, will provide farmers with online access to needed knowledge: the human expert farmers would otherwise rely on gains time for research and for expanding his or her expertise (40).

New information technologies will also revolutionize dairy record-keeping. For example, milk data are typically recorded once during a 30-day interval and extrapolated to predict total milk for that period. With new automatic metering devices, milk weights could be recorded from each milking. For a 305-day lactation, this would increase the data points from 12 to 710, if the cow is milked twice a day. With appropriate data-handling tools, this information could be tied to other information, such as measures of milk conductivity and temperature, and profiles developed to monitor cows for estrus. This would allow increased reproductive efficiency, while reducing labor requirements, and decrease the need for visual observation.

CONCLUSIONS

Advances in biotechnology and information technology will revolutionize the dairy industry. Attention by farm groups, consumers, and policymakers has focused on the first major biotechnology product from this new era—bST. In the future bST will be surpassed by more advanced biotechnology methods in animal reproduction, transgenic animal production, and animal health technologies. The more advanced technologies, for example, will increase a cow's endogenous bST production and milk synthesis by inactivating genes that inhibit bST production, eliminating the need to administer bST exogenously. Similar advanced technologies will produce higher quality cows, improve disease prevention and management, and allow for the production of high-value pharmaceuticals in milk.

These advanced biotechnologies will require sophisticated management capability to use them effectively. Knowledge-based information systems will assist in providing this management capability. Expert systems, for example, can help farmers integrate information for decisionmaking. To effectively use these systems farmers will need access to software that is specific to their individual situation and feasible for use in a variety of economic and policy situations.

The technologies from this new era are in various stages of development. Some of these technologies, such as embryo transfer, recombinant DNA vaccines, and information systems, are already commercially available or will be soon. Other technologies, such as transgenic cattle and advanced reproductive technologies, will not be available until the end of the decade. The next chapter examines the collective effect these emerging technologies, including bST, will have on the dairy industry in the economic and policy environment of the 1990s.

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Chapter 5

Economic and Policy Impacts of Emerging Technologies on the U.S. Dairy Industry

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Chapter 5

Economic and Policy Impacts of Emerging Technologies on the U.S. Dairy Industry

Technologies from the biotechnology era will play an important role in sustaining or accelerating the historical trend of constantly increasing milk output per cow. The new technology likely to have the most to do with this growth is bovine somatotropin (bST). In the following analysis of the economic and policy implications of emerging technologies, special emphasis will be given to bST. As with any analyses, the conclusions are only as accurate as the assumptions made. Of special interest and importance is the assumption regarding the adoption of bST by farmers.

TECHNOLOGY ADOPTION

It is not known when and how many dairy farmers will adopt new technologies, such as bST, once they become commercially available. Several studies of bST either directly address the issue of adoption or make assumptions regarding adoption rates and patterns. In a survey of dairy farmers, Lesser et al. (6) found that about 50 percent of respondents would adopt bST within the first year of its commercial availability, and that over 80 percent would within 3 years. Most analysts, relying heavily on such studies, have tended to assume relatively rapid adoption of bST (1,4).

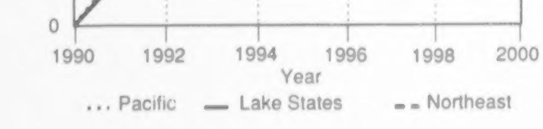
However, the use of surveys to indicate prospective adoption rates of a technology that is not yet available is problematic. For example, information regarding the technology is incomplete. Most of the bST surveys were done several years ago when there was little negative reaction from public interest groups. Moreover, new dairy technologies, as a general rule, have not tended to be adopted rapidly. For example, despite having been available commercially for over 40 years, artificial insemination technology is used only by 65 to 70 percent of dairy farmers. Likewise, Dairy Herd Improvement (DHI) technology, available for 50 years, is used by only 45 percent of farmers (13). In addition, regionally variable patterns of use are associated with both technologies.

This report considers the history of technology adoption by farmers for insight into potential rates of bST adoption. Statistical analyses indicate that the variables most closely (and positively) related to farmer adoption of new technologies (e.g., automatic grain-feeding systems, automatic milking-unit removal, three-times-a-day milking, DHI, and artificial insemination) were milk output per cow and size of herd. Efficiency in the utilization of capital, labor, and feed were also found to be significantly related to technology adoption in particular regions (7).

Using this information, and assuming that adoption of bST would closely parallel that of other technologies, bST technology adoption curves were derived (see figure 5-1). (See app. A for details.) Comparative regional information on the level of adoption after 1, 5, and 10 years is contained in table 5-1. The results reflect:

- the tendency of the dairy industry to adopt technologies at different rates regionally;
- the progressiveness of the Pacific region dairy industry compared with that of other regions, including traditional milk production regions; and
- a slower rate of adoption than is indicated by producer surveys of probable bST use, and one that is more typical of past dairy industry technology adoption patterns.

Figure 5-1—Comparative bST Adoption Curves Projected for the Pacific, Lake States, and Northeast Regions



SOURCE: Office of Technology Assessment, 1991.

Table 5-1—Forecasted Adoption Rates for bST Technology, Selected Years, 1991-2000[a]

	Percent of farmers adopting		
Region	1991	1995	2000
Pacific	17%	46%	67%
Lake States	15	35	46
Northeast	15	31	43
Appalachia	15	32	46
Southeast	15	29	39
Southern Plains	13	34	42
Corn Belt	13	25	31

[a]bST is assumed to be commercially available in 1991.

SOURCE: Office of Technology Assessment, 1991.

OTA's analysis indicates that during the first year that bST is commercially available, no more than 17 percent of farmers will use it. After 5 years, bST adoption is forecast to range from 25 percent in the Corn Belt to 46 percent in the Pacific region. After 10 years, bST adoption is forecast to range from 31 percent in the Corn Belt to 67 percent in the Pacific region.

NATIONAL AND REGIONAL IMPACTS UNDER ALTERNATIVE DAIRY POLICIES

Future milk-supply prices and dairy farmer returns are determined by the interactions of technology adoption, consumer demand, and dairy policy, as established in the 1990 farm bill. These interactions were captured using a national computer simulation model referred to as LIVESIM with the following assumptions:[1]

- regional adoption curves as indicated in the preceding section;
- output per cow increases 1.5 percent per year in base scenario without bST;
- output per cow increases 1,320 pounds annually with use of bST;[2]
- bST is injected for 150 days annually;
- cost of bST use is $0.30 per cow per day;
- feed efficiency increases by 5 percent due mainly to bST; and
- the minimum level of government purchases by the Commodity Credit Corporation to satisfy food program needs (i.e., school lunch program, etc.) is 3.0 billion pounds annually.

The policy options analyzed included a fixed price support, a price support trigger, and a quota program. It is important to keep in mind that this analysis begins with the industry in relative supply-demand balance and in the absence of strong incentives for either increased or reduced production (10).

Fixed Price Support

This option fixes the price support level at $10.60 per cwt ($0.50 per hundredweight (cwt) higher than the level authorized by the 1990 farm bill) for all years and serves as a useful bench mark for policy option comparisons. In this scenario, the government purchases excess milk, at the support price, in order to clear the market. Without bST, milk production would increase progressively under this scenario from a projected 144 billion pounds in 1990 to 152 billion in 1995 (see table 5-2). With bST, production would increase an additional 4 to 5 billion pounds over the period 1994 to 1998; annual government purchases for food programs would rise as high as 9.0 billion pounds, but generally increase by 3 to 4 billion pounds over the minimum (3 billion pounds) (see table 5-3).

Support Price Adjusted by Trigger

This option, similar to policy from 1985-1990, triggers a price support reduction each time the level of government purchases rises above 5.0 billion pounds annually. This option resembles the assessment option in the 1990 farm bill that effectively will trigger reductions in producer returns as milk price declines. The simulation period begins with a milk support price of $10.60 per cwt. This is adjusted downward in $0.50 per cwt increments in any year that expected government purchases are greater than 5 billion pounds. Without bST, a single price support reduction brings the support price to $10.10 per cwt in 1991. With bST, two price support reductions are triggered; one in 1991 and another in 1993, reducing the price support level to $9.60 per cwt. These price reductions moderate production increases to keep

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[1] LIVESIM was developed by D.S. Peel, Department of Agricultural Economics, Oklahoma State University. App. B provides a description of the model and detailed results of the analysis.

[2] The increase in output per cow in a given herd tends to be closer to an absolute number of pounds of milk than to a percentage increase. Therefore, approximately the same increase in pounds of milk produced per cow might be expected in comparably managed herds with cows each producing 12,000 to 20,000 pounds of milk per year.

Table 5-2—Level of Milk Production, With and Without bST, Under Alternative Policy Scenarios, 1990-98 (billions of pounds)

	Policy scenarios					
	Fixed support		Trigger		Quota	
Year	With bST[a]	Without bST	With bST[a]	Without bST	With bST[a]	Without bST
1990	144	144	144	144	144	144
1991	145	144	146	144	146	144
1992	146	143	146	143	145	144
1993	153	150	153	150	148	146
1994	153	149	152	148	150	148
1995	156	152	156	152	152	150
1996	157	153	155	153	155	153
1997	160	155	159	155	157	155
1998	161	157	159	157	160	157

[a] bST is assumed to be commercially available in 1991.

SOURCE: Office of Technology Assessment, 1991.

Table 5-3—Level of Government Purchases, With and Without bST, Under Alternative Policy Scenarios, 1990-98, Milk Equivalent (billions of pounds)

	Policy scenarios					
	Fixed support		Trigger		Quota	
Year	With bST[a]	Without bST	With bST[a]	Without bST	With bST[a]	Without bST
1990	3.0	3.0	3.0	3.0	3.0	3.0
1991	7.3	5.3	7.3	5.3	7.3	5.3
1992	4.3	3.0	3.0	3.0	3.5	3.0
1993	9.0	5.7	6.8	3.8	3.4	3.0
1994	6.0	3.0	3.0	3.0	3.1	3.0
1995	7.0	3.0	3.0	3.0	3.0	3.0
1996	4.8	3.0	3.0	3.0	3.0	3.0
1997	5.3	3.0	3.0	3.0	3.0	3.0
1998	3.6	3.0	3.0	3.0	3.0	3.0

[a] bST is assumed to be commercially available in 1991.

SOURCE: Office of Technology Assessment, 1991.

Commodity Credit Corporation (CCC) purchases near the 3.0-billion-pound minimum (see table 5-3).

Milk Production Quota

Several proposals have been made to improve supply control in Federal dairy policy. Quota systems utilized in California and Canada, for example, have been suggested for use nationally in the United States. While these systems differ in their implementation, each results in a much stronger opportunity for management of excess dairy production. In the simulation model, control of milk production is accomplished by reducing the number of cows in a herd. In practice, these reductions might be triggered by a two-tiered pricing system or some other mechanism that provides disincentives for producing over quota levels.

The quota policy is designed to maintain government purchases at or near the minimum government use target of 3.0 billion pounds. The quota is adjusted downward any year CCC purchases exceed 3.0 billion pounds. The price support remains at $10.60 per cwt; however, the market price is allowed to adjust as under the other options. The quota yields a much stabler market price, one that is generally higher than that under the trigger option. However, with bST a tendency still exists for the price to rest at the support level. The quota avoids the high level of government purchases necessary under the fixed price support scenario (see table 5-3).

Regional Impacts

Substantial controversy has arisen over the potential regional impacts of bST and other emerging technologies. The results of this analysis suggest a continuation of current trends toward greater concentration of production in the Pacific region and the largest decline in the Corn Belt. Shifts in future market shares will be largely a function of differences in rates of adoption of bST and other technologies. The more rapid rate of bST adoption predicted for the Pacific region will increase its market share even faster than the historical trend.

Regional shifts in production patterns could be moderated by changes in farm policy. The market mechanism, as reflected in the trigger price support mechanism, places the greatest pressure on higher cost producers and regions. The fixed price support blunts the price declines associated with supply increases, thus providing a degree of protection to higher cost regions. Quotas tend to freeze production patterns. Thus, the regional impacts of bST and other technologies could be reduced through the adoption of a quota policy. However, by freezing production patterns, quotas discourage efficiency. The benefits of the quota tend to be capitalized in fixed-asset values, thus raising costs, particularly to new entrants to the industry (i.e., new entrants must buy quota from current dairy operators). And, because dairy farmers would not want to see a valuable asset (quota) lose its value, it would also be difficult to discontinue a quota policy.

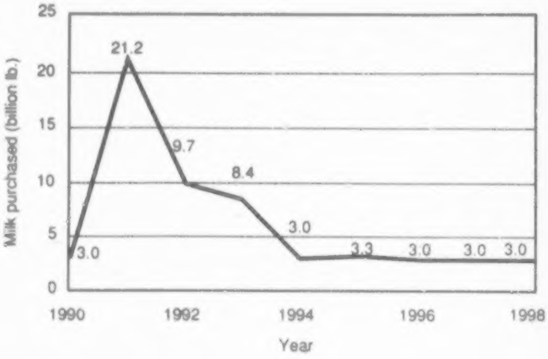
NATIONAL IMPACTS UNDER ALTERNATIVE DEMAND AND SUPPLY SCENARIOS

Many claims have been made concerning the potential adverse health impacts of milk produced with bST. While these claims remain unsubstantiated, consumer perceptions can be more important than reality in determining market demand. As indicated previously, initiatives to label milk produced by cows receiving bST could create a perception that consumption of this milk may not be desirable. Since policy needs to be designed considering the full range of potential developments, two scenarios regarding reduced milk consumption were analyzed. One of these involved a substantial but temporary reduction in demand followed by recovery to a smaller long-term reduction. The second involved a large permanent reduction.

Small Demand Reduction

The small reduced-demand scenario drops per-capita demand by 10 percent (about 55 pounds) in 1991, 5 percent in 1992 (i.e., demand increases from 1991 to 1992), and 2.5 percent permanently thereafter. The effects of these reductions are CCC purchases totaling 21.2 billion pounds (14.5 percent of production) in 1991, 9.7 billion pounds in 1992, and 8.4 billion pounds in 1993 (see figure 5-2). The analysis assumed a continuation of the trigger milk-price support policy. The support trigger decreases the price support level down to $9.10 per cwt in 1994. In 1994, the industry begins to stabilize at the 3.0-billion-pound minimum purchase level. Even though government purchases are exceedingly high for 3 years, the trigger mechanism seems to accommodate a small demand reduction quite well.

Figure 5-2—Projected Impact of a Temporary Demand Reduction on Government Milk Purchases Under Trigger Price Policy, 1990-98



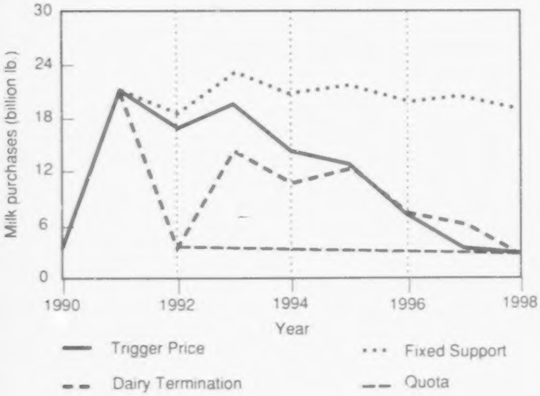
SOURCE: Office of Technology Assessment, 1991.

Large Demand Reduction

The second reduced-demand scenario assumes a permanent 10-percent reduction in per-capita consumption. If the price support is sustained at $10.60 per cwt under the fixed support scenario, CCC purchases continue at a level that approaches or exceeds 20 billion pounds of production through 1998 (see figure 5-3). This would exact a high cost to the government.

While the trigger mechanism copes reasonably well with a small permanent consumption reduction, the industry has difficulty adjusting to a large permanent demand reduction scenario with this mechanism. The support price must be triggered down to $7.60 in 1997 in order to bring CCC purchases to below 4 billion pounds. Such a low support price would make it difficult (impossible) for even the best managed dairy farms to avoid economic losses. As indicated in figure 5-3, for each of the years 1991 to 1995, the CCC is purchasing at least 12 billion pounds (at least 8 percent of the milk supply).

Figure 5-3—Projected Impact of a 10-Percent Permanent Demand Reduction on Government Purchases Under Alternative Dairy Policies, 1990-98



SOURCE: Office of Technology Assessment, 1991.

Under this reduced demand scenario, a dairy termination program might be considered as an alternative to the severe price support reduction discussed above. A termination program involves a one-time buyout of dairy cows, to be implemented when government purchases reach a certain level. In the model, the level was established at 15 billion pounds annually. When government purchases reach this level, enough dairy cows would be liquated the following year to eliminate the excess production.

Such a termination policy would be triggered in 1992 because at least 21 billion pounds of CCC purchases would have occurred in 1991 (see figure 5-3). The herd kill to bring CCC purchases down to the minimum 3.0 billion pounds would be 1.3 million cows (13.1 percent of the herd). In the process, cow prices would fall by $6.11 per cwt (12 percent) with a 6.1-percent drop in beef cattle prices. (See app. B.)

Once the termination is completed, milk production bounces back and CCC purchases exceed 14 billion pounds in the next year (1993). This result is similar to that of the 1986 Dairy Termination Program. The lowest producing cows on average are liquated from the industry. The higher producing cows remain, providing the industry with the capability of responding to increased prices. Another termination probably would not be feasible because of the high cost associated with the program and the tendency of farmers to bid up the cost of selling out. However, the support price still would decline to $7.60 per cwt in 1998—a year later than under the trigger option without the termination program, once again verifying that termination programs do not result in permanent reductions in supply.

If a quota were imposed in 1992 with the objective of bringing CCC purchases back down to the minimum 3.0 billion pounds, 12.2 percent of the dairy herd (1.2 million cows) still would be sent to market (slaughtered) in order to reduce the herd to about 8.8 million cows. This compares with 1.3 million cows slaughtered under the termination program. Under the quota, the dairy cow price falls 8.1 percent (compared with 12.0 percent under the termination program) while the beef cattle price falls by 4.3 percent (compared with 6.1 percent under the termination program). Perhaps more important, the quota program effectively controls milk supply. (See app. figure B-13.)

This analysis suggests that if a large permanent reduction in demand occurred, changes in dairy policy would most likely be needed. A fixed support price policy would be too costly and a trigger price policy or producer assessments would be too severe to producers. The policy alternatives are a termination program or a quota. A termination program is costly and does not result in permanent reductions in supply. A quota program does effectively control supply and, compared to the termination program, is less costly. Benefits of a quota tend to be capitalized into fixed asset values, thus raising the costs to new entrants and making it difficult to discontinue the quota policy. Thus, consideration should be given to observing CCC purchases over a 2-year period, as opposed to 1 year, before a quota is implemented. This would help to determine whether demand reduction is permanent or temporary.

Large Supply Increase

Previous survey-based analyses of the impact of bST typically assume a considerably higher rate of adoption than this study predicts, based on past adoption patterns. If bST results in a 15-percent increase in the milk supply in the first year, instead of the 5-percent increase used in the above analysis, CCC purchases rise to at least 20 billion pounds. Large supply increases could be realized not only through rapid adoption of bST, but also as firms that participated in the 1986 Dairy Termination program reenter the market beginning in 1991.

The impact of a 15-percent supply increase would be similar to that of a 10-percent permanent demand reduction, i.e., CCC purchases equal 20 billion pounds in the first year (see app. figure B-12). In both instances, it takes 5 years for the price support trigger mechanism—even with a price support as low as $7.60—to bring CCC purchases down from 20 billion pounds to no more than 10 billion pounds. The problems of managing large government purchases over such a long period suggests the need to consider production management options. Here again, the termination program only reduces production temporarily with substantial negative impacts on beef prices. Quotas are effective at controlling production but also negatively affect beef prices, although not to the same degree as a single termination option.

FARM LEVEL IMPACTS

The combined impacts of emerging technologies, dairy policies, regional differences in production costs, and long-term industry trends can be more easily visualized at the level of individual dairy farms. Representative farms are briefly described in table 5-4. The parameters of representative farms were originally developed for OTA in 1985 and have since been continuously updated by Agricultural and Food Policy Center faculty and staff at Texas A&M University. The farms are simulated with and without bST adoption utilizing the FLIPSIM model.[3]

The farm level impacts of the three policy scenarios—fixed support price, trigger, and quota—were analyzed over the period 1989 to 1998. It was assumed that the same farm program provisions operated over the 10-year period. The initial analyses were conducted assuming no change in demand. Subsequently, alternative demand assumptions were analyzed (11).

Alternative Dairy Policies

The analysis indicates that once bST becomes available, there will be strong incentives to adopt the technology. Regardless of the region, the payoffs from bST adoption are substantial. For example, with the trigger price policy, the 52-cow Upper Midwest dairy, a typical, moderate-size dairy farm in this region, enhances its chance of survival (probability that the farm will remain solvent through 1998) from 58 to 74 percent by adopting bST once it becomes available (see table 5-5). The same is true for large dairies (see table 5-6). Nonadopters of bST have more problems surviving and, therefore, are more likely to exit the industry.

Tables 5-5 and 5-6 provide insight into competitive conditions in the dairy industry and the reasons for regional shifts in milk production patterns. Regardless of size, Upper Midwest farms have problems realizing sufficient earnings to achieve a reasonable return on equity, compete, and survive. While Northeast farms perform better, they too were found to be at a disadvantage relative to the Pacific and Southeast farms.

These results raise questions about the advisability of State laws placing a moratorium on the use of bST. Dairy farmers located in States that have put a moratorium on adoption will be placed at a substantial disadvantage relative to those in unrestricted States. If moratoriums are imposed in regions where farm survival probabilities are already low (relative to other regions), the impact of a moratorium can be particularly severe.

Policies and the choice between bST adoption or nonadoption operate together to impact survival in a number of ways (see table 5-7). Higher earnings resulting from the fixed price support increase the probability of survival for a 125-cow Upper Midwest dairy and the chances of a 5-percent return on initial equity. However, even with adopting bST, net worth continues to erode.

Surprisingly, perhaps, the quota program performs worse than either the trigger price or the fixed price support. This is because the quota price objective is the same as the fixed price support ($10.60) and because restrictions on output curb expansion and raise costs per cwt. Thus, if a quota is to be imposed, the price objective must be sufficiently high to offset the effects of lower production (higher production costs per cwt) or producers could be worse off.

The absolute economic payoff from bST adoption is about the same under a trigger price policy and a

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[3] FLIPSIM was developed by J.W. Richardson, Department of Agricultural Economics and C.J. Nixon, Department of Accounting, Texas A&M University (12). App. C provides a description of the model and detailed results of the analysis.

Table 5-4—Summary Characteristics of Representative Moderate-Size and Large Dairy Farms, by Region

	Upper Midwest		Northeast		Southwest[a]		Southeast	
Characteristic	Moderate	Large	Moderate	Large	Moderate	Large	Moderate	Large
Cow numbers	52	125	52	200	350	1,500	200	1,500
Output/cow (pounds)	16,850	16,850	17,940	17,830	18,590	19,690	15,340	15,310
Total asset value ($000)	470	940	608	1,395	1,097	3,858	1,569	7,723
Land value ($000)	133	295	274	640	118	492	813	4,591
Percent of feed raised	63	60	50	46	0	0	25	2

[a] Includes farms from both the Pacific and Mountain USDA production regions.

SOURCE: Office of Technology Assessment, 1991.

Table 5-5—Impacts of bST Adoption on the Economic Viability of Moderate-Size Representative Farms, Assuming No Change in Demand for Milk Due to bST, Trigger Price Policy, by Region, 1989-98 (in percent)

	52-cow Upper Midwest		52-cow Northeast		350-cow Southwest		200-cow Southeast	
Measure of impact	Non-adopter	bST adopter	Non-adopter	bST adopter	Non-adopter	bST adopter	Non-adopter	bST adopter
Probability of survival[a]	58%	74%	100%	100%	95%	97%	100%	100%
Probability of earning 5-percent return on equity	58	74	100	100	95	97	100	100
Probability of increasing equity[b]	0	0	3	3	60	79	13	24
Present value of ending net worth as percent of beginning net worth[c]	16	29	72	77	109	128	76	89

[a] Chance that the individual farm will remain solvent through 1998, i.e., maintain more than a 10-percent equity in the farm.

[b] Chance that the individual farm will increase its net worth in real 1989 dollars through 1998.

[c] Present value of ending net worth divided by initial net worth indicates whether the farm increased (decreased) net worth in real dollars.

SOURCE: Office of Technology Assessment, 1991.

Table 5-6—Impacts of bST Adoption on the Economic Viability of Large Representative Farms, Assuming No Change in Demand for Milk Due to bST, Trigger Price Policy, by Region, 1989-98 (in percent)

	125-cow Upper Midwest		200-cow Northeast		1,500-cow Pacific		1,500-cow Southeast	
Measure of impact	Non-adopter	bST adopter	Non-adopter	bST adopter	Non-adopter	bST adopter	Non-adopter	bST adopter
Probability of survival[a]	95%	99%	100%	100%	100%	100%	100%	100%
Probability of earning 5-percent return on equity	90	95	99	100	100	100	100	100
Probability of increasing equity[b]	8	12	43	53	100	100	88	99
Present value of ending net worth as percent of beginning net worth[c]	57	69	92	102	195	214	129	147

[a] Chance that the individual farm will remain solvent through 1998, i.e., maintain more than a 10-percent equity in the farm.

[b] Chance that the individual farm will increase its net worth in real 1989 dollars through 1998.

[c] Present value of ending net worth divided by initial net worth indicates whether the farm increased (decreased) net worth in real dollars.

SOURCE: Office of Technology Assessment, 1991.

Table 5-7—Impacts of bST Adoption on the Economic Viability of Representative Large (125-cow) Upper Midwest Farms Under Alternative Dairy Policies, Assuming No Change in Demand for Milk, 1989-98 (In percent)

	Trigger price		Fixed price support		Quota	
Measure of impact	Non-adopter	bST adopter	Non-adopter	bST adopter	Non-adopter	bST adopter
Probability of survival[a]	95%	99%	99%	100%	85%	92%
Probability of earning 5-percent return on equity	90	95	95	98	67	78
Probability of increasing equity[b]	8	12	11	18	2	3
Present value of ending net worth as percent of beginning net worth[c]	57	69	67	78	37	46

[a] Chance that the individual farm will remain solvent through 1998, i.e., maintain more than a 10-percent equity in the farm.
[b] Chance that the individual farm will increase its net worth in real 1989 dollars through 1998.
[c] Present value of ending net worth divided by initial net worth indicates whether the farm increased (decreased) net worth in real dollars.

SOURCE: Office of Technology Assessment, 1991.

fixed support price policy for the representative dairy farms (see table 5-8). Increasing the price of milk by maintaining the milk support price at its current level does not greatly increase the economic incentive to adopt bST, but that incentive is significantly lower if a quota is in effect. This suggests that the rate of bST adoption would be slowed by imposing a quota rather than continuing the trigger price policy.

Table 5-8—Comparison of Average Annual Economic Payoffs From bST Adoption for Eight Representative Dairy Farms Under Three Alternative Dairy Policies, Assuming No Change in Milk Demand, 1989-98[a] (thousands $)

	Policy scenarios		
Region/size	Trigger price	Fixed support	Quota
Lake States:			
Moderate	3.9	4.1	2.4
Large	10.3	10.9	7.0
Northeast:			
Moderate	3.4	3.6	1.0
Large	15.8	16.6	8.8
Southwest:			
Moderate	26.5	26.6	18.3
Large	90.5	91.7	61.2
Southeast:			
Moderate	21.9	22.8	17.2
Large	166.4	166.3	132.0

[a] Economic payoffs from bST are the average annual change in net cash farm income between a nonadopter and a bST adopter over the 1989 to 1998 planning horizon. The payoff is net of the cost of bST, the added transportation costs for milk, and the additional feed.

SOURCE: Office of Technology Assessment, 1991.

Alternative Demand and Supply Scenarios

Potential reductions in demand due to consumer concern over bST would reduce the economic payoffs from using this technology. The most significant result of such demand reduction is reduced economic viability of all dairy farms, and particularly of those in the Midwest. For example, the economic payoff for bST adoption is $10,300 for the 125-cow dairy in the Upper Midwest if there is no decrease in milk demand. If demand decreased slightly, the economic payoff falls to $9,200 and if the demand decrease is large, the economic payoff declines to $6,900. Thus, the incentive to adopt and the rate of adoption would be reduced if milk demand declines.

The adverse impacts of reduced demand could be countered by either a termination program (in the event of a small reduction in demand) or by a quota (if larger reductions in demand occurred).[4] However, even with reduced demand, there would be strong incentives to adopt bST for all farms in all regions. For example, with a continuation of the trigger policy, a 52-cow Upper Midwest dairy's probability of survival declines to 40 percent under a small decrease in demand; adopting bST boosts survival probability under this scenario to 48 percent (see table 5-9). Similar trends hold true for the larger dairies (see table 5-10). Thus, the economic payoff for bST adoption is positive; those who adopt bST will experience greater probabilities of survival and

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[4] Small and large demand reductions are the same as explained in the previous section. A small demand reduction assumes that milk demand would decrease 10 percent in 1991, 5 percent in 1992 (i.e., demand increases from 1991 to 1992), and 2.5 percent each year in 1993-1998. A large demand reduction assumes that milk demand would decrease 10 percent in each year 1991-1998.

Table 5-9—Impacts of bST Adoption on the Economic Viability of Moderate-Size Representative Farms, Assuming Small Decrease in Demand for Milk Due to bST, Trigger Price Policy, by Region, 1989-98 (in percent)

	52-cow Upper Midwest		52-cow Northeast		350-cow Southwest		200-cow Southeast	
Measure of impact	Non-adopter	bST adopter	Non-adopter	bST adopter	Non-adopter	bST adopter	Non-adopter	bST adopter
Probability of survival[a]	40%	48%	100%	100%	88%	94%	99%	100%
Probability of earning 5-percent return on equity	40	48	100	99	88	94	89	94
Probability of increasing equity[b]	0	0	1	2	35	51	4	9
Present value of ending net worth as percent of beginning net worth[c]	3	10	65	70	79	99	58	71

[a] Chance that the individual farm will remain solvent through 1998, i.e., maintain more than a 10-percent equity in the farm.

[b] Chance that the individual farm will increase its net worth in real 1989 dollars through 1998.

[c] Present value of ending net worth divided by initial net worth indicates whether the farm increased (decreased) net worth in real dollars.

SOURCE: Office of Technology Assessment, 1991.

Table 5-10—Impacts of bST Adoption on the Economic Viability of Large Representative Farms, Assuming Small Decrease in Demand for Milk Due to bST, Trigger Price Policy, by Region, 1989-98 (in percent)

	125-cow Upper Midwest		200-cow Northeast		1,500-cow Pacific		1,500-cow Southeast	
Measure of impact	Non-adopter	bST adopter	Non-adopter	bST adopter	Non-adopter	bST adopter	Non-adopter	bST adopter
Probability of survival[a]	85%	91%	100%	100%	100%	100%	100%	100%
Probability of earning 5-percent return on equity	68	82	98	99	100	100	100	100
Probability of increasing equity[b]	2	7	26	45	96	98	65	86
Present value of ending net worth as percent of beginning net worth[c]	40	50	86	95	162	180	110	127

[a] Chance that the individual farm will remain solvent through 1998, i.e., maintain more than a 10-percent equity in the farm.

[b] Chance that the individual farm will increase its net worth in real 1989 dollars through 1998.

[c] Present value of ending net worth divided by initial net worth indicates whether the farm increased (decreased) net worth in real dollars.

SOURCE: Office of Technology Assessment, 1991.

economic success than nonadopters. The positive economic payoffs for bST adoption are greater under the dairy termination program than under the trigger price policy. Thus, bST adoption would be accelerated even with declining milk demand if a termination program were introduced in lieu of the trigger price policy.

The supply impacts estimated by the LIVESIM model in the previous section were based on past adoption practices, not farmer survey results, which indicate higher adoption for bST. If the survey results are accurate predictors of adoption then a large increase in supply would occur. Unless supply controls such as a dairy termination program or a quota are imposed, adverse impacts on economic viability would be substantial (see app. tables C-12 to C-17).

Enhancing the Survival of Traditional Farms

Results of the preceding analysis indicate that smaller, less efficient, farms will have difficulties realizing sufficient earnings to achieve a reasonable return and survive even with the adoption of bST. Northeast farms perform better, in part, because they receive higher Federal milk marketing order prices. Farms that do not adopt bST will feel even more severe impacts.

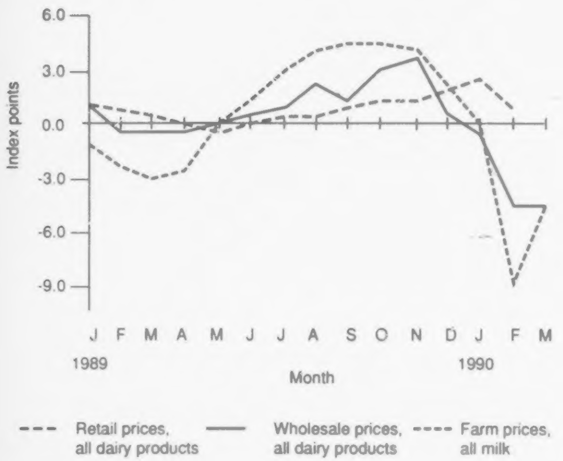
The economic viability of smaller farms may be enhanced by changes in scale of operation, progressiveness in technology adoption, research and extension, and dairy policy. The following provides a brief discussion of the importance of each item.

- *Scale of Operation*—Generally, larger farms experience lower costs of production. Studies now in progress indicate that in the Upper Midwest and Northeast, economies of size have resulted in the establishment of larger herds that have the potential to realize even more economies of size involved in dairying. Farms with herds larger than 125 cows in the Upper Midwest and 200 cows in the Northeast will be more likely to lower their costs of production and compete than smaller operations.
- *Technology Adoption*—A key to achieving the economic benefits of a new technology is to adopt it early. The traditional milk production regions have a history of lagging behind other regions in adopting new technology. This study has shown that, based on experience, the Upper Midwest and Northeast regions will lag behind the Pacific region by more than 20 percent in the adoption of bST. Ways must be found to encourage producers in these regions to adopt new technology earlier to enhance their probability of economic success.
- *Research and Extension*—Little, if any, emphasis is given to conducting research and providing extension services to different-size farms. Small, moderate, and large farms each have their own unique problems, particularly from a management perspective. Research is needed on developing management strategies for each farm size. Extension strategies also need to be developed to assist farmers in technology adoption so they can receive more of the benefits of new technologies. Laggards in technology adoption receive little economic pay-off.
- *Dairy Policy*—Based on this study's analysis, a fixed support price policy provides farms in the traditional milk-producing regions with higher earnings that increase their probability of survival and the chance of earning a 5-percent return on equity. However, even with this policy, net worth continues to erode for these farms. Thus, the support price may need to be increased. This is, of course, more costly in terms of government expenditures. An alternative would be to target these farms for a higher support price—but it still will be more costly and administratively complex compared to other alternatives. However, if substantial progress were made on the items discussed above possibly no change in policy would be needed.

BENEFICIARIES OF TECHNOLOGICAL CHANGE

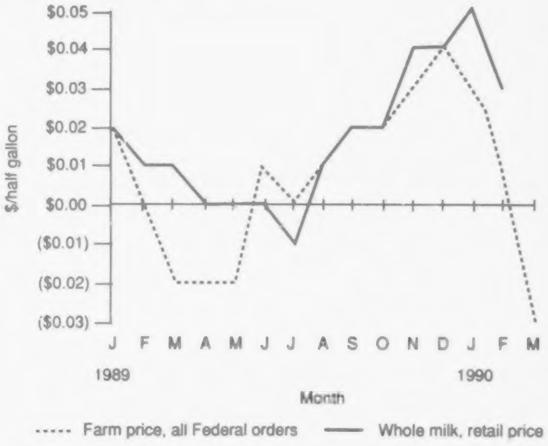
The issue of who benefits from technological change is not new but is relevant to this study. The farm-level results indicate that bST adopters are better off than nonadopters. First adopters, moreover, are the greatest beneficiaries of any technological change. They receive a relatively high price for their product and realize the cost reductions resulting from bST use. As more farmers adopt, the market price falls, which makes the consumer the ultimate beneficiary. As the market price falls, farmers who do not adopt may be forced out of business.

Figure 5-4—Dairy Price Indexes at Three Market Levels (change from prior month)



SOURCE: Compiled from U.S. Department of Agriculture dairy statistical data by Andrew Novakovic, *Dairy Marketing Notes*, 1990, No. 2, Department of Agricultural Economics, Cornell University, Ithaca, NY.

Figure 5-5—Farm and Retail Prices of Beverage Milk Per Half Gallon (change from prior month)



[a] This is the producer price for fluid milk (Class I) averaged over all Federal milk marketing orders.

SOURCE: Compiled from U.S. Department of Agriculture dairy statistical data by Andrew Novakovic, *Dairy Marketing Notes*, 1990, No. 2, Department of Agricultural Economics, Cornell University, Ithaca, NY.

Questions have been raised regarding whether consumer prices do, in fact, decline as producer prices fall. Some groups opposing the approval of bST have attempted to show that retail milk prices do not fall as producer prices decline and, therefore, consumers do not benefit from the technology (3). A review of the relevant data on producer prices received and retail dairy prices paid do not support this contention.

Novakovic (8) made a comparison of the changes in dairy prices at the farm, wholesale, and retail levels for 1989 through 1990. Figure 5-4 illustrates the monthly changes in average aggregate farm, wholesale, and retail dairy prices converted to an index where 1982 to 1984 = 100. The graph shows a change in each index from one month to the next. (A line on the graph below (above) 0.0 indicates prices fell (rose) compared to the prior month.)

The data show that farm, wholesale, and retail prices did follow each other. There are, however, differences in the volatility of change. Farm prices are the most volatile while retail prices are the least. Declines in farm prices are reflected in smaller declines at retail. However, this is true on the up side as well. Farm prices increased the most from mid 1989 to the end of 1989 and retail prices increased the least.

A review of actual price changes for fluid milk and manufactured products, i.e., cheese, provides a more insightful analysis (8).[5] The pattern in figure 5-5 is similar but not identical to figure 5-4. That is producer and retail prices for fluid milk did follow one another up and down.[6] Producer prices, however, decreased more than retail prices in the first half of 1989 and increased less in the second half. Some buoyancy exists to retail milk prices relative to farm prices in reflecting declines in farm prices.

Price changes in cheese markets offer a similar but more responsive change (see figure 5-6). Note that producer prices lag wholesale prices by 1 month and retail prices have a 2- to 4-month lag in reflecting wholesale price changes. For example, the largest increase in wholesale cheese prices begin in May. Retail price increases began to increase in August and peaked in October. By then wholesale prices were increasing at a more modest rate while retail prices were increasing by the largest amount. Examining just the October data, it would be difficult to justify a 9-cent increase in retail prices by a 2-cent increase in the wholesale price. It can, however, be justified by the 5 months of 4- to 8-cent monthly increases in wholesale prices that occurred prior to October. Also note that in the second half of the year, the increase in producer prices was substantially greater than the increase in retail prices. These results are similar to other research in this area. Kinnucan and Forker (5) found the same asymmetric relationship between farm and retail dairy prices. This phenomena is found in other agricultural industries as well.[7]

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[5] Percentage changes are not the best way to compare farm, wholesale, and retail prices. When expressed in a common unit of measurement (e.g., dollars per cwt of milk), the farm price will obviously be a smaller number than the retail price. Thus taking a percentage of a smaller number is less than an equal percentage of a larger number. Part of the seemingly lower volatility in prices higher up the marketing channel is a result of comparing index or percentage changes.

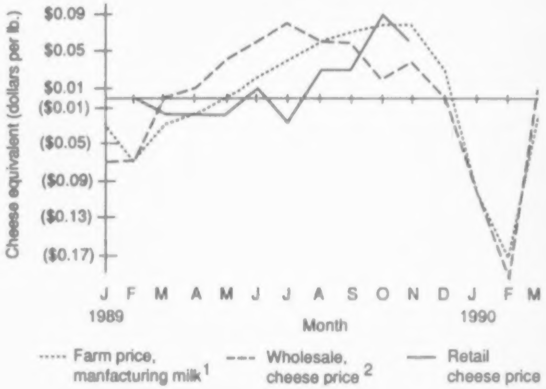
[6] The same result was found by Outlaw et al. (9) in a more recent analysis.

This analysis indicates that prices of dairy products to consumers are reflective of changes in supply and demand factors in the market. Individual dairy products such as milk and cheese do respond to price changes differently, reflecting the specific forces at work in each of their respective markets. Retail milk prices follow farm price increases but seem to be relatively slower in reflecting farm price declines. On the other hand, cheese prices are responsive to farm price changes and may even start falling before producer prices. Thus, technological change that lowers farmers' production costs will eventually be reflected in the market and the corresponding savings passed on through lower prices to the consumer, the ultimate beneficiary.

INTERNATIONAL TRADE PROSPECTS

Speculation exists that adoption of new technologies, such as bST, will enhance the U.S. position in international milk markets. The U.S. dairy industry primarily focuses its marketing efforts on the domestic market. It has had limited success in international markets. This has been due to a number of factors including: difficulties in identifying markets, monetary policies, import restrictions, and political uncertainty in many countries. Moreover, the world market price for dairy products is lower than the U.S. price—largely because of the use of subsidies to increase export sales from competing countries.

Figure 5-6—Farm, Wholesale, and Retail Prices of Cheese (change from prior month)



[a] The farm price is the Minnesota-Wisconsin price which is also the Class III (manufacturing) price in Federal milk marketing orders.

[b] The wholesale price is the National Cheese Exchange (NCE) price for 40 lb block of cheddar.

SOURCE: Compiled from U.S. Department of Agriculture dairy statistical data by Andrew Novakovic *Dairy Marketing Notes*, 1990, No. 2, Department of Agricultural Economics, Cornell University, Ithaca, NY.

Cost-reducing technologies, such as bST, can improve the United States competitive position in international milk markets, but alone are not sufficient. An encompassing strategy that at a minimum identifies promising new markets, benefits from favorable monetary policies, addresses export subsidies and import restrictions, as well as supports research to provide cost-reducing technologies for the industry will be needed.

POLICY IMPLICATIONS

The dairy industry is familiar with and has gained strength from technological change. The constant adoption of new technology has resulted in a relatively uniform annual increase in output per cow in the range of 1.5 to 2.0 percent annually. Emerging technologies in the 1990s, especially bST, may temporarily accelerate that rate of increase, putting the industry on a higher output-per-cow growth path.

The impact of bST on the dairy industry is heavily weighted by the rate of adoption of the new technology. Experience in adoption of dairy technologies suggests slower rates of adoption than has been predicted by farmer survey. However, this analysis still indicates substantial economic incentives for, and payoffs from, adoption of bST. The analysis also indicates that States placing a moratorium on the use of bST run substantial risk of damaging the economic viability of their dairy farmers.

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[7] Hahn (2), for example, found that the farm, wholesale, and retail prices for beef and pork show significant evidence of asymmetric price interactions. That is, prices display greater sensitivity to price-increasing shocks than to price-decreasing shocks.

The rates of adoption indicated by past technology adoption trends suggest that a mechanism that allows producer returns to decline as CCC purchases increase, i.e., a trigger policy or producer assessment (as provided for in the 1990 farm bill) could effectively adjust supply to meet demand without exceedingly large inventory accumulations. However, if sharp demand reductions were to accompany the introduction of bST, supply management policies such as production quotas or termination (buy-out) programs may be required. Termination programs, such as the one implemented in 1986, are costly and not effective in reducing supply over a period of time. Production quotas can effectively control supply. However, quotas do result in freezing regional production shifts and since the quota has an economic value, make it more costly for new entrants into the industry.

Regardless of farm size or region, there will be strong economic incentives to adopt bST. However, Upper Midwest farms adopting the new technology still will have problems realizing sufficient earnings to achieve a reasonable return on equity, compete, and survive. Northeast farms perform better but they too are at a disadvantage relative to the Pacific and Southeast farms. For farms not adopting the new technology the dilemma will be even more severe. These results raise questions about the advisability of State laws, especially in the Upper Midwest, that place a moratorium on the use of bST. To enhance the economic viability of farms in these regions changes in scale of operation, progressiveness in technology adoption, research and extension policy, and perhaps dairy policy may be required.

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Appendixes

Appendix A

A National and Regional Analysis of the Adoption of bovine Somatotropin

Chapter 5 presented the summary results of the national, regional, and farm-level impacts of emerging technologies and public policies on the U.S. dairy industry. A crucial assumption in the analyses is the rate of adoption of bovine somatotropin (bST). This appendix discusses the results of the analysis supporting OTA's adoption rates for bST. For more detail than is provided in this appendix the reader is advised to read the background paper on which this analysis is based.[1]

Review of Previous Studies

There have been numerous studies dealing with the introduction of bST into the dairy industry (1,2,5,6,7,9). Lesser, Magrath, and Kalter (7) estimated the rate of adoption of bST based on a primary survey of producer attitudes towards the technology. This estimate has been used in simulation studies of bST (6), which predict the relatively rapid adoption of bST after it is introduced. Fifty percent of dairy herds adopt bST technology within the first year and over 80 percent within 3 years.

Other studies (i.e., Fallert et al. (2) and Sellschopp and Kalter (9)) reviewed the impact of bST under alternative policy scenarios. Their conclusions were that with the introduction of bST, inflexible support prices would result in large Commodity Credit Corporation (CCC) purchases during the 1990s. To reduce government purchases, the government would need to continue reducing the support price by $0.50 increments.

Using a structural model, Kaiser and Tauer also analyzed the impact of bST on the national dairy market during the 1990s under a number of government policy options. Under one, CCC purchases are held stable by adjusting the U.S. herd inventory through repeated implementation of the dairy termination program. The authors note that such adjustments may be difficult to accomplish if farmers recognize the intent of the government and raise their dairy termination program bids. Without these adjustments, CCC purchases rapidly increase with bST even with lower support prices. The authors conclude that a combination of price support reductions and dairy termination programs would be the most effective policy for balancing the conflicting interests of dairy producers, taxpayers, consumers, and beef producers.

The previous analyses have relied on surveys and hypothetical estimates for the adoption rates of bST. The studies have generally lacked a consistent economic foundation for predicting adoption. This is in part because a model that systematically explains technological change and/or the consequences for agricultural policy has been elusive. As Feder (3) and Just and Zilberman (4) observe, conventional economic models have not consistently explained adoption patterns of agricultural innovations or why seemingly profitable technologies are slowly adopted by specific classes of farms (i.e., small farms). The analysis here attempts to predict adoption of bST.

Technological Change

Technological change refers to change in production processes that results from the application of scientific knowledge. At the firm level, technological change can be realized in several ways. It can be *embodied* in inputs (changes in input quality); it can be *disembodied*, and involve improved use of existing resources such that a higher output rate per unit of input is obtained; or it can arise from entirely new processes and new inputs (e.g., bST). A combination of these three phenomena underlies many innovations. For example, the development of hybrid corn varieties represented the embodiment of scientific knowledge in corn seed. Disembodied management knowledge was then needed for its successful use, and eventually a set of new inputs in the form of pesticides was developed for use with the hybrids.

These definitions apply to the analytical framework presented here. The adoption of bST is both the consequence and cause of technological change. To use bST successfully, farmers must adjust to new, higher production levels by increasing technical efficiency. Farmers with low levels of efficiency are less likely to adjust inputs to meet the requirements of higher milk production. Conversely, the higher the current productivity of the farmer, the more likely he or she will adopt bST technologies.

Operational Model of bST Adoption

In a theoretical model outlined by McGuckin (8), changes in technical efficiency (ratio of milk output to farm resources) drive the adoption of new technologies. Milk output per cow (a productivity measure) and changes in scale (size of the dairy unit) are strongly correlated with technical efficiency and thus technology adoption. As productivity increases over time so does adoption of new technologies.

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[1] This appendix is based on the OTA commissioned background paper "Adoption of bovine Somatotropin: A National and Regional Analysis" prepared by J. Thomas McGuckin, New Mexico State University. It is available through the National Technical Information Service.

The linkages between productivity change, technical efficiency, and adoption of bST are the cornerstone of this analysis. However, because of data limitations, only general trends in productivity over time can be obtained. Increasing farm productivity is equivalent to increasing farm technical efficiency, which drives adoption: as productivity increases because of improved technical efficiency, so does the willingness to adopt new technologies such as bST.

The operational model used in this analysis assumes that a farm's likelihood of adopting bST is a function of its scale and technical efficiency (measured by total factor productivity (TFP)). Because predicting adoption of bST is ex ante, an index of adoption of previous technologies (outlined in the data section) is used as a proxy measure. The empirical model used is the following general representation:

$$IA_f = g(S_f, TFP_f), \text{ for } f = 1..\ N$$

where IA is an index of adoption of previous technologies. S is scale or size of the dairy, TFP is total factor productivity and f represents a cross section of dairy farms.

Data

The analysis used cross sectional representative farm data from the 1985 U.S. Dairy Farm Costs and Return Survey. Detailed data sources and the types of information collected through the survey are reported in the USDA report by Fallert, McGuckin, Betts, and Bruner (2). The data include dairy farm milk production, amount of labor (both hired and family), amount of capital (converted to a cow capacity basis—parlor, housing, and feeding system can be rated by the number of cows milked per day) and respective prices. As the index for the technological adoption, five type of technologies were weighted according to their relevance to bST adoption. The five technologies include:

1. automatic grain feeding system (parlor or otherwise),
2. automatic milking unit takeoff,
3. three times a day milking,
4. herd production records (DHI), and
5. artificial insemination.

The most heavily weighted (45 percent) measure was 3x milking. Use of this technology indicates that a farmer can adjust feed, breeding, and herd health practices to a higher level of production. However, 3x requires additional labor while bST would not. Artificial insemination, an improved method of breeding that directly affects milk production, is weighted 20 percent. DHI is a management information system, known as Dairy Herd Improvement, that is weighted 15 percent. Automatic takeoffs are representative of automated milking systems (weighted 15 percent); automatic grain feeders are similar to automatic takeoffs, though not universally used by factory style operations.

The rate of change in the index of technological adoption indicates the change in use of the bST technology over time and across dairy production regions of the United States. Because the estimated functions are indices, an initial starting point was derived. A range of initial adoption levels (low, medium, and high) were identified for each region.

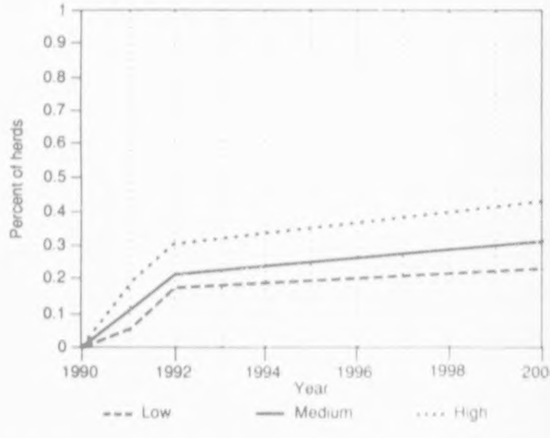
Results

To predict the adoption of bST, a regression analysis was used based on historical rates of change in capital, labor, and feed efficiency in the dairy industry. The results for each region contain a low, medium, and high scenario for the initial adoption of the technology in 1991. After 1991, all regional growth in adoption is based on the relative impact of production efficiency change on the technological index. The results are presented by region.

The Corn Belt region is one of the lowest adoption regions (see figure A-1). By 1995, between 20 and 35 percent of herds will receive bST (low and high scenarios, respectively). By 2000, these percentages rise to 25 and 45 percent, respectively. A medium scenario is 31 percent.

The Southeast is also relatively slow to adopt (see figure A-2). By 1995, between 24 and 42 percent of herds will receive bST (low and high scenarios, respectively).

Figure A-1—Projected Adoption Rate of bST, Corn Belt Region



SOURCE: Office of Technology Assessment, 1991

Figure A-2—Projected Adoption of bST, Southeast Region

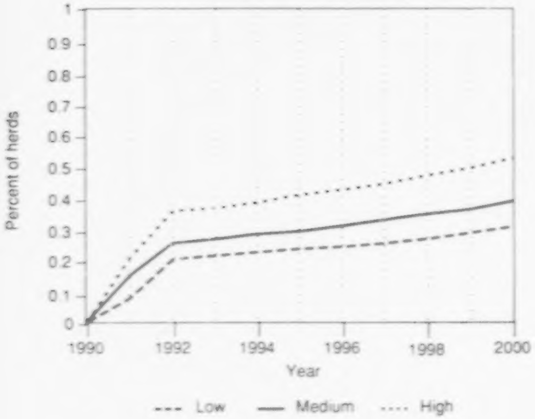


Figure A-3—Projected Adoption Rate of bST, Southern Plains Region

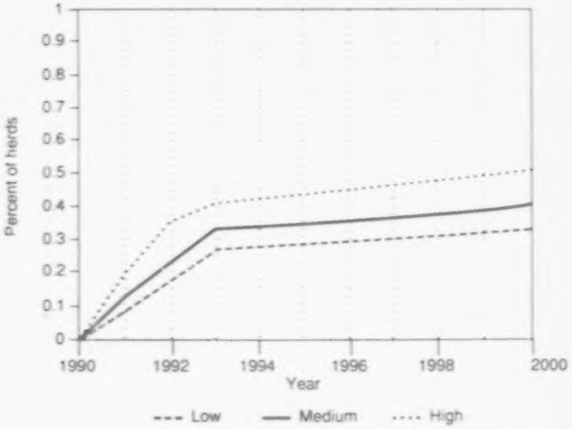


Figure A-4—Projected Adoption of bST, Lake States Region

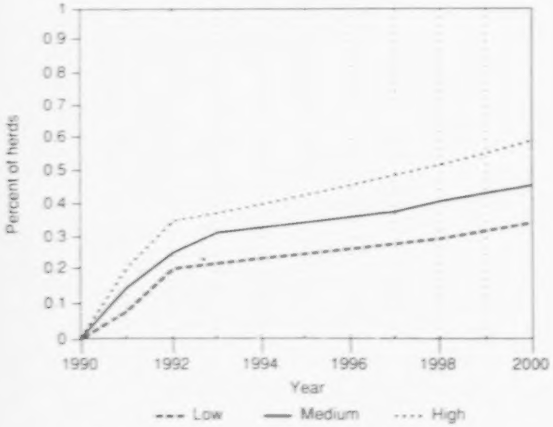


Figure A-5—Projected Adoption Rate of bST, Appalachian Region

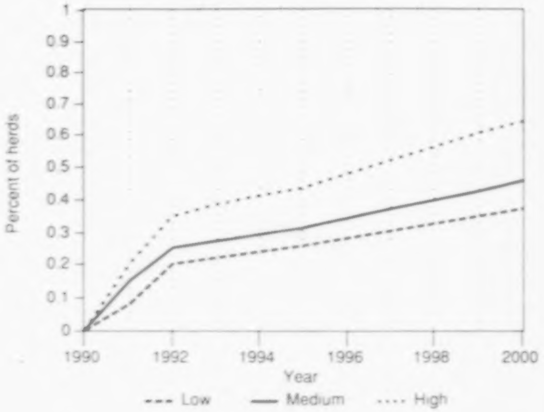


Figure A-6—Projected Adoption of bST, Northeast Region

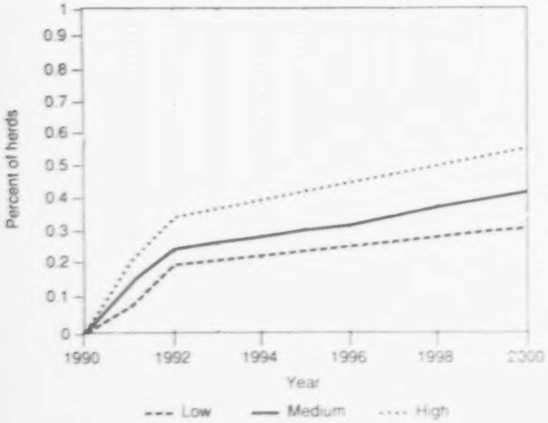
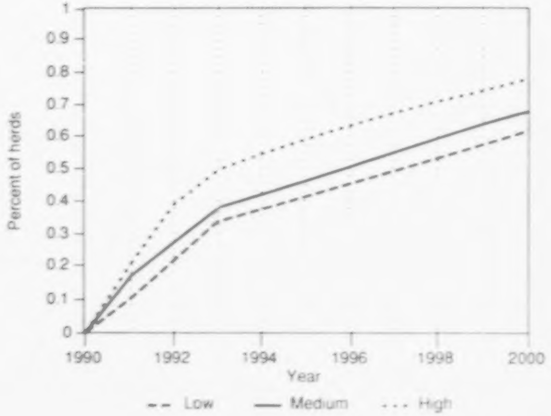


Figure A-7—Projected Adoption Rates of bST, Pacific Region



SOURCE: Office of Technology Assessment, 1991.

By 2000, these percentages rise to 32 and 55 percent, respectively. A medium scenario is 39 percent. (However, confidence in these predicted rates is low, respectively.)

Like the Southeast, the Southern Plains is a low adoption region (see figure A-3). By 1995, between 28 and 44 percent of herds will receive bST (low and high scenarios, respectively). By 2000, these percentages rise to 35 and 53 percent, respectively. A medium scenario is 42 percent.

Adoption rates are slightly higher in the Lake State region (see figure A-4). By 1995, between 26 and 46 percent of herds will receive bST (low and high scenarios), respectively. By 2000, these percentages rise to 37 and 64 percent, respectively. A medium scenario is 46 percent.

Relatively high rates of adoption are also predicted for the Appalachian region (see figure A-5). By 1995, between 27 and 48 percent of herds will receive bST (low and high scenarios. respectively). By 2000, these percentages rise to 40 and 70 percent, respectively. A medium scenario is 46 percent.

Adoption rates in the Northeast are similar to those in the Lake States (see figure A-6). By 1995, between 25 and 44 percent of herds will receive bST (low and high scenarios, respectively). By 2000, these percentages rise to 34 and 59 percent, respectively. A medium scenario is 43 percent.

The adoption pattern in the Pacific Region, the fastest growing dairy region of the United States, is accelerated relative to that of all other regions (see figure A-7). By 1995, between 45 and 63 percent of herds will receive bST (low and high scenarios, respectively). By 2000, these percentages rise to 66 and 81 percent, respectively. A medium scenario is 67 percent. The strong coefficients of size and milk output per cow drive the adoption of bST in this region at a high rate.

Overview of Results

The dairy industry has one of the highest rates of productivity increases in U.S. agriculture. Yet, adoption of existing proven technologies is not universal among dairy producers. Though technologies such as artificial insemination and herd record systems have existed for many years, these technologies have only been adopted by 30 to 40 percent of producers in several major dairy regions. The most technically efficient producers (highest ratio of milk output to farm resources) are the most likely to adopt new technologies. Using regression techniques, this analysis establishes that producers with high levels of milk per cow and large operations are more likely to adopt new technologies (a finding consistent with scientific literature on adoption of new technologies).

Given that bST has similar characteristics to previous dairy technologies, improvement in productivity from an increasing knowledge base will drive its adoption. Analysis of productivity measures in the major dairy regions suggest that between 50 and 70 percent of dairy producers in the United States will adopt bST by the year 2000. The Pacific region will lead all regions in adoption, possibly reaching 80 percent by 2000.

The projected rates of adoption in this analysis are lower than other studies based on differing methodologies. Rather than basing predictions on historical trends, for example, Lesser, McGrath, and Kalter use contingent surveys of producers and arrive at higher adoption rates. There is little to suggest that the adoption of bST will vary from past adoption practices by dairy operators. bST is simply a continuation of numerous other productive technologies in the dairy industry. The lower projected rates of adoption are, therefore, the more realistic projections of actual adoption rates.

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Appendix B

Detailed National and Regional Impacts of bovine Somatotropin and Other Emerging Technologies Under Alternative Dairy Policies

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The national policy evaluations in chapter 5 were conducted with an econometric-simulation model of the U.S. agricultural sector (AGSIM). AGSIM is a disaggregated agricultural-sector model that utilizes econometric supply and demand relationships for major crop and livestock commodities. Figure B-1 illustrates the conceptual framework of the simulation model. The model contains regional supply representations of major crop commodities and an annual livestock supply sector. For this study a regional dairy supply component was incorporated into the model to analyze regional impacts of technology adoption under alternative dairy policies. National demand relationships for all crop and livestock commodities are utilized in the model.[1]

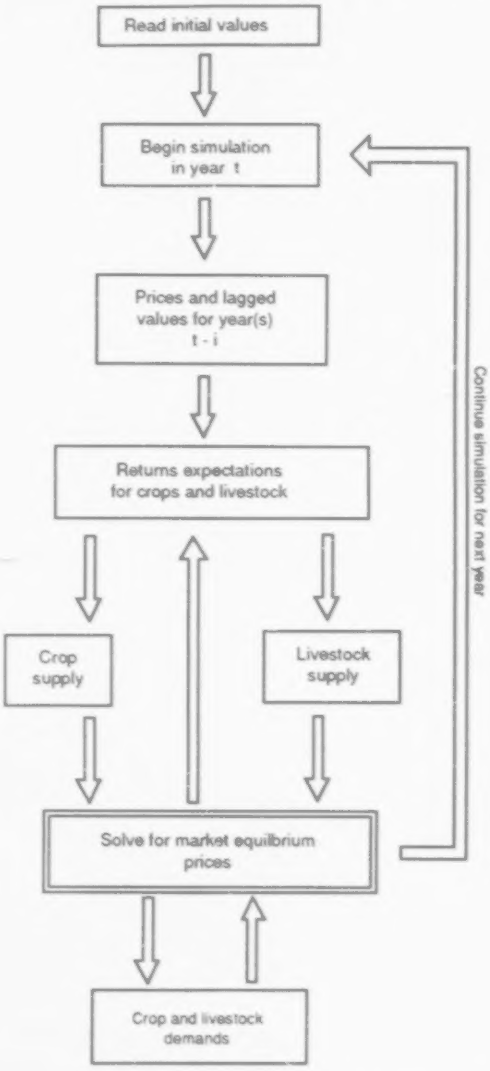
Supply relationships in the model are specified as functions of expected returns to production. Thus, aggregate supply relationships directly reflect the microlevel impacts of policies or technological change that change revenue components (e.g., yield) or cost components (e.g., product cost) or both. Further details of the crop portion of the model and regarding use of the model for policy analysis are contained in Taylor (2,3).

The livestock model (LIVESIM) utilized in the agricultural-sector model described above was developed by Peel (1). LIVESIM contains separate market representations for fed beef, nonfed beef, pork, broilers, turkey, milk, lamb, eggs, and veal. The original aggregate supply relationships for milk production were replaced by regional supply equations.

Of particular importance for this study is the disaggregation of beef and dairy sources as contributors to fed and nonfed meat supplies in the model. The indirect impacts of dairy policy alternatives on other livestock subsectors are captured endogenously (within the model) through changes in fed and nonfed beef supply. Changes in dairy returns influence not only milk production but also impact calf crop, cow slaughter, and calf slaughter. The importance of these impacts was highlighted by the controversy over the dairy termination program of 1986. That program caused a significant decline in cattle prices.

Crop and livestock sectors are directly linked in the market in LIVESIM. Livestock returns (which drive livestock supply equations) are partly determined by feed

Figure B-1—Simulation Model


Read initial values
Begin simulation in year t
Prices and lagged values for year(s) t - i
Returns expectations for crops and livestock
Crop supply
Livestock supply
Solve for market equilibrium prices
Crop and livestock demands
Continue simulation for next year

SOURCE: D.S. Peel, "National and Regional Impacts of bovine Somatotropin Adoption Under Alternative Dairy Program Policies," OTA commissioned background paper, Washington, DC, 1990.

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[1] This appendix is based on the OTA commissioned background paper "National and Regional Impacts of bovine Somatotropin Adoption Under Alternative Dairy Program Policies" prepared by Derrell S. Peel, Oklahoma State University. It is available through the National Technical Information Service.

costs calculated internally from feed rations and crop prices. Changes in crop prices directly impact livestock returns and thus livestock supply. In turn, total livestock production in part determines demands for the individual crops and influences crop prices accordingly.

The Regional Dairy Model

For this analysis, total milk supply is determined from regional equations for milk production per cow and dairy cow inventory. Data for the econometric estimates were aggregated from State data. Ten regions, consistent with the standard USDA production regions (discussed in ch. 2), were used in the model. Dairy returns for each of the regions is based on a USDA data series known as the regional cost of production budgets for dairy.

Market-clearing prices are calculated by balancing raw milk production, on a per-capita basis, against per-capita milk demand. The resulting national milk price is regionalized in the model via regressions of regional milk price on national milk price. These regional price relationships implicitly capture the net effect of the classified pricing system on regional milk prices.

Modeling Dairy Policy

The econometric-simulation model captures the primary impacts of milk price support programs by calculating milk and dairy returns based on the maximum equilibrium market price or on an exogenously specified milk support price. Thus milk production per cow, dairy herd inventory, dairy replacement inventory, and the dairy impact on cow slaughter and calf crop all reflect the influence of the milk support price.

Government support of milk production is treated on a raw milk equivalent (ME) basis. Since the government only purchases manufactured milk products, all government purchases are made at a manufacturing milk price, which is assumed to be $1 per hundredweight (cwt) less than the all-milk price.

This analysis assumes that a minimum level of government milk purchases of 3 billion pounds of milk annually will be required for program needs. Government may purchase more than this minimum level to balance milk supply and demand at the prevailing support price.

Modeling Technology Adoption

The impacts of bovine Somatotropin (bST) adoption and other emerging technologies were incorporated into the econometric-simulation model under the following assumptions:

1. output per cow increases 1.5 percent per year in base scenario without bST,
2. output per cow, due to bST, increases 1,320 pounds annually,
3. the daily cost of bST is $0.30 per cow,
4. cows are treated for 150 days annually,
5. overall feed efficiency is improved by 5 percent for treated cows.

The model increases feed use marginally for additional milk production resulting from bST use. However, feed required per cwt of milk production is 5 percent lower with bST because cow maintenance requirements are spread over more units of production. The model also assumes that per cwt variable costs for other production expenses increase incrementally with bST use.

Three alternative rates of industry adoption of bST (low, medium, and high) were considered for the 10 production regions of the United States. Complete presentation of the development and assumptions of the alternative adoption rates are presented in appendix A.

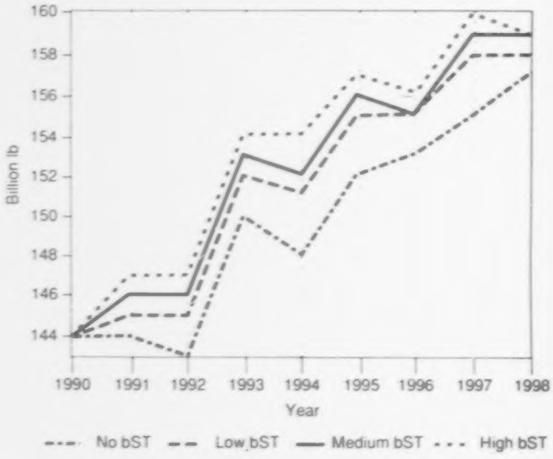
Results

Various combinations of the policy alternatives described above and the alternative adoption rates for bST were analyzed. In addition, the possibility that bST adoption could have some exogenous impact on milk demand was considered in several scenarios.

Impact of bST Adoption

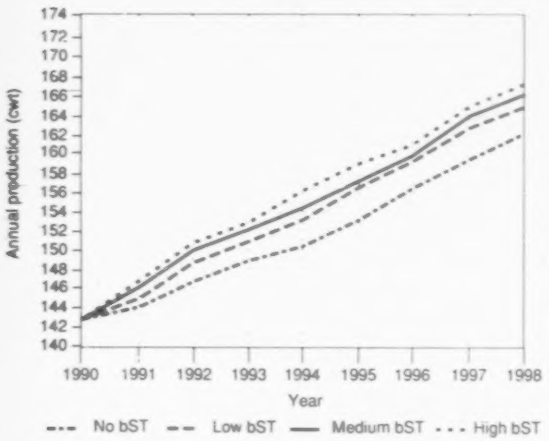
Of primary concern in formulating dairy policy is the impact that bST adoption will have on total milk production and consequently on government purchases related to the dairy program. Figure B-2 shows total milk production under different levels of bST adoption. This figure assumes an annual trigger adjustment for milk support price. The maximum impact in terms of addi-

Figure B-2—Projected Total Milk Production With Trigger Policy Under Alternative bST Scenarios



SOURCE: Office of Technology Assessment, 1991.

Figure B-3—Projected Milk Production per Cow



SOURCE: Office of Technology Assessment, 1991.

tional milk production occurs in 1994, with total production of 154 billion pounds under high bST adoption compared with 151 billion pounds under low bST adoption. Figure B-3 shows the impact of bST on milk cow productivity.

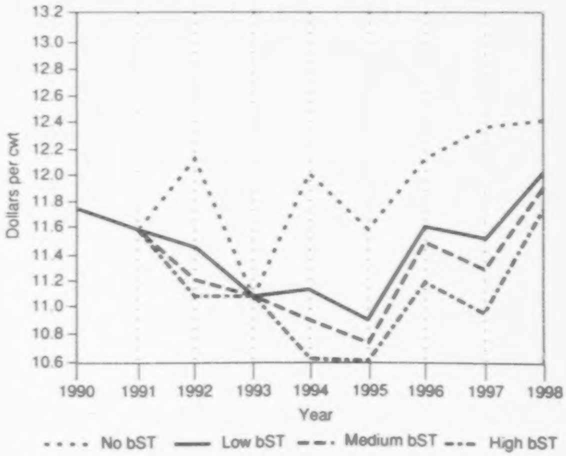
Differences in milk production due to alternative levels of bST adoption would be more pronounced if the milk support price was not triggered down (see figure B-4). With no bST, the baseline simulation of the model results in a single $0.50 per cwt adjustment in milk-support price from $10.60 to $10.10 in 1992. Under each of the three alternative levels of bST adoption, an additional $0.50 per cwt decrease to $9.60 in 1994 is required to keep government purchases of milk under the 5 billion pound level. Figure B-5 shows the high levels of government purchases of milk in 1991 and 1993 that precipitate the reductions in milk support price.

Comparison of Alternative Policies

The implications of bST adoption depend on the policy scenario under which adoption takes place. This section considers the impacts of alternative policy options on milk production and price under the assumption of a medium level of adoption.

Figure B-6 shows total milk production under the fixed support price, annual trigger, and quota policies. The impact of the dairy termination (buyout) program is not included in this section because government milk purchases never exceed 15 billion pounds—the amount assumed to initiate a buyout program. Milk production generally increases to similar levels under each of the policies. However, milk production is lowest for the quota and highest for the fixed support scenario for most years. The trigger policy results in milk production levels between those associated with the other two policies and production that is somewhat more variable from year to year.

Figure B-4—Projected All Milk Price With Trigger Policy Under Alternative bST Scenarios



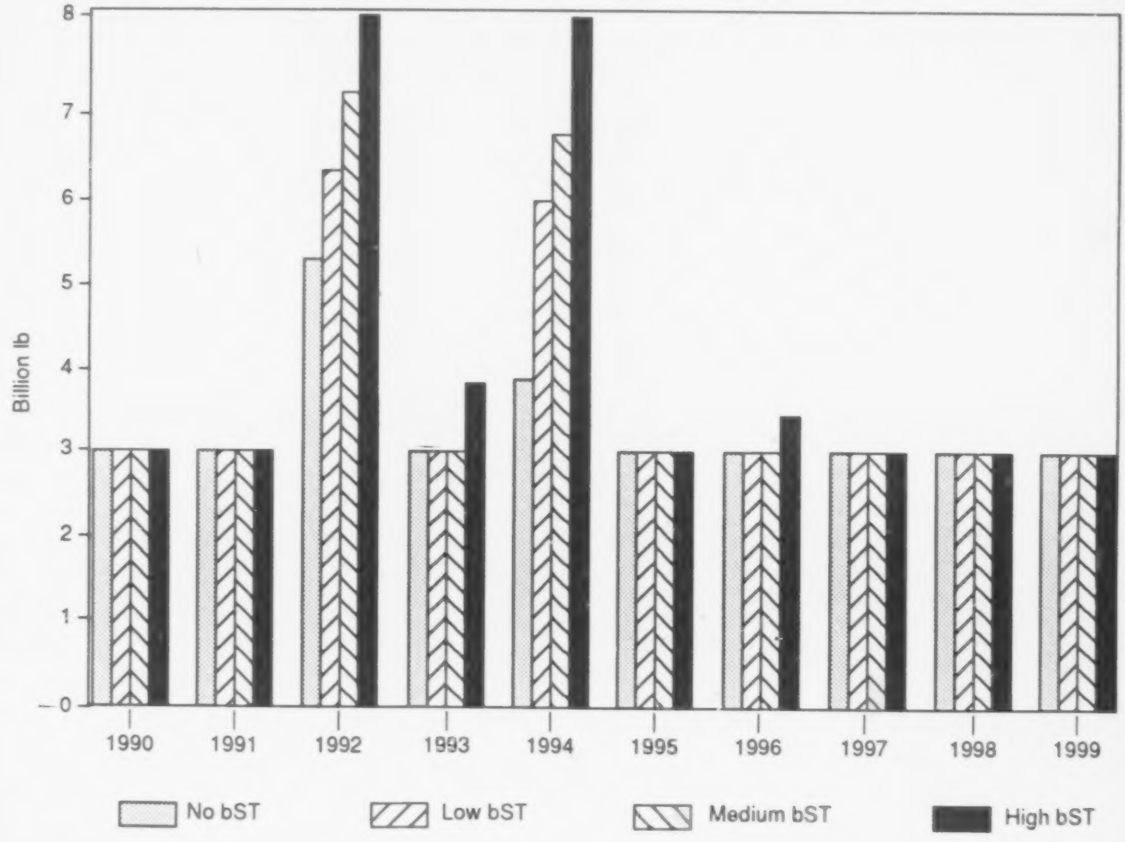
SOURCE: Office of Technology Assessment, 1991.

The fixed support price and quota scenarios maintain a milk support price of $10.60 (see figure B-7). The all-milk price is $1.00 greater than the manufacturing price of milk. Beginning in 1995, milk price under the quota policy begins to rise over the support level. In contrast, the trigger policy allows milk price to fall substantially before it rises again as the industry cuts production.

The impacts of the alternative policies on government purchases of milk are summarized in figure B-8. As expected, the fixed support price policy is the most expensive, resulting in government purchases well above the minimum milk purchase level in order to maintain the support price. The quota and trigger policies are able to keep government purchases much lower although the trigger is slower to compensate for the impact of bST adoption. Annual government purchases between 1991 and 1998 average about one-third less under the trigger policy compared to the fixed support price.

The trigger and quota policies accomplish their goals by different means. All of the policies result in increased government purchases for milk in 1991, the first year of bST adoption. However, it is assumed that within a year the quota policy is able to reduce the size of the dairy herd to a level that limits government purchases for excess milk and maintains the milk price at the higher support price ($10.60). The trigger policy reduces the support price in 1992 and again in 1994 before controlling government purchases of excess milk.

Figure B-5—Projected Government Milk Purchases With Trigger Policy Under Alternative bST Scenarios



SOURCE: Office of Technology Assessment, 1991.

Regional Impacts

In addition to concerns over the national impacts of bST adoption under different policy scenarios are concerns about how the technology will affect the industry's regional structure and dynamics. One way to summarize what the regional impacts of bST adoption might be is to analyze changing milk production patterns across the Nation.

Figure B-9 shows total production shares for the 10 production regions of the country in 1990 and 1998. This chart assumes a trigger policy for adjusting milk support price and a medium level of bST adoption. Trends already observed in the dairy industry continue in this simulation. Declining market shares are noted for the Corn Belt and the Northern Plains with smaller reductions in the Delta, Appalachian, and Southeast. Largest increases in market share are noted in the Pacific region. The Lake States and Northeast maintain roughly their current market shares over this period.

Figure B-10 shows the impact of alternative policies on regional market shares, with medium level of bST adoption. There is little difference between the impact of the fixed support price and that of trigger policies in regional market shares. The quota does not allow market shares to change as much as the other policies. Rather, the quota is assumed to fix market shares at 1990 levels. Some change occurs because of trends in milk cow productivity even though the dairy herd is fixed in size.

Alternative Demand Scenarios

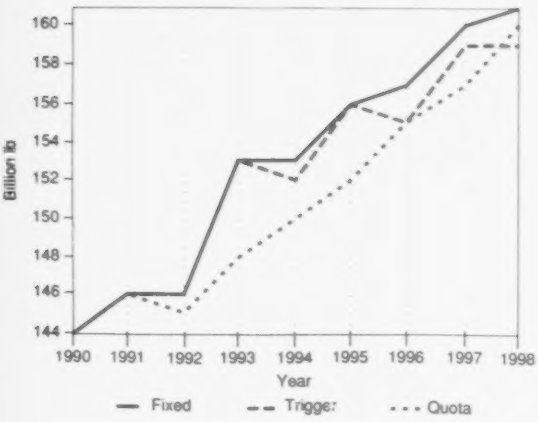
Continued consumer concern over bST prompted consideration of scenarios with exogenous changes in milk demand reflecting adverse consumer reaction to bST in milk. Three alternative demand scenarios were compared in the model:

Baseline: used in all previous scenarios

Temporary: large temporary demand reduction with small permanent demand reduction

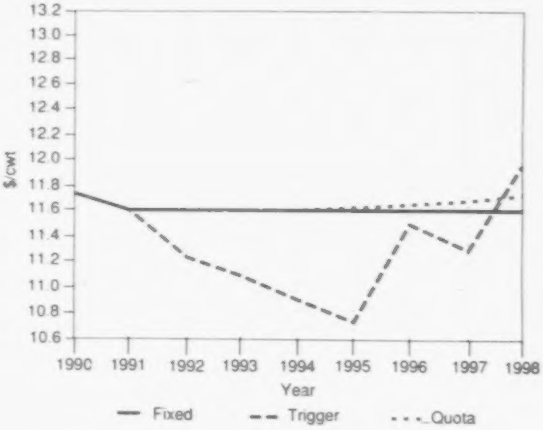
Permanent: large permanent demand reduction

Figure B-6—Projected Total Milk Production With Medium bST Adoption Under Alternative Dairy Policies



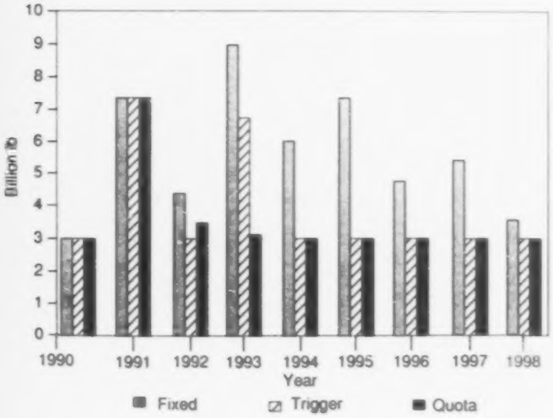
SOURCE: Office of Technology Assessment, 1991.

Figure B-7—Projected All Milk Price With Medium bST Adoption Under Alternative Dairy Policies



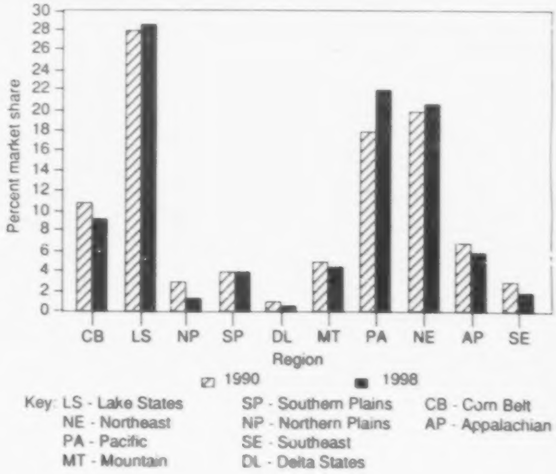
SOURCE: Office of Technology Assessment, 1991.

Figure B-8—Projected Government Milk Purchases With Medium bST Adoption Under Alternative Dairy Policies



SOURCE: Office of Technology Assessment, 1991.

Figure B-9—Actual and Projected Regional Milk Market Shares With Trigger Price Policy, 1990 and 1998.



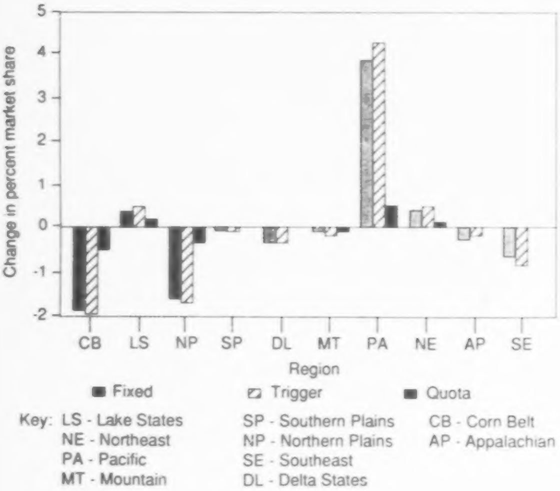
SOURCE: Office of Technology Assessment, 1991.

Details of these alternative demand scenarios are presented in chapter 5.

Alternative Milk Demand Under Current Policy—Figure B-11 illustrates the impacts of alternative milk demands assuming a continuation of the current trigger policy for adjusting milk support price and the medium level of bST adoption. Changes in milk demand have large implications for milk price. While the base level of demand results in milk price near $12 per cwt for all years, a permanent large demand reduction would allow milk price to fall as low as $8.60 in 1997 before beginning to rise.

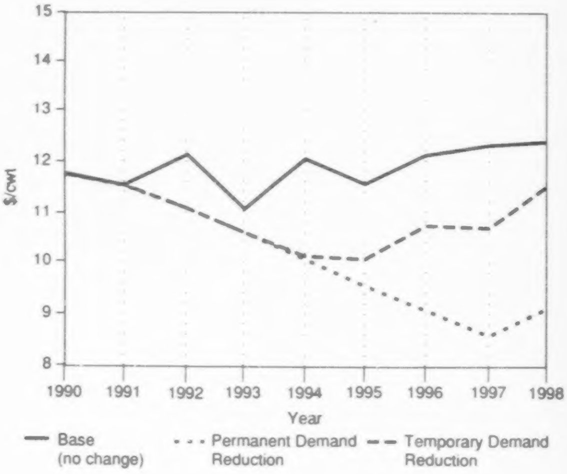
Figure B-12 shows the level of government milk purchases under the different levels of demand. Reduced

Figure B-10—Projected Change in Milk Market Shares for Alternative Dairy Policies Between 1990 and 1998



SOURCE: Office of Technology Assessment, 1991.

Figure B-11—Projected All Milk Price With bST Adoption Under Alternative Milk Demands



SOURCE: Office of Technology Assessment, 1991.

milk demand, under both demand reduction scenarios, results in government milk purchases of 21 billion pounds in 1991 at a cost of about $2.5 billion. With the temporary demand reduction, government purchases decline fairly rapidly as the support price declines. With the permanent large demand reduction, however, government purchases decline slowly as the trigger lowers support price.

Policy Comparison With Permanently Reduced Milk Demand—In the face of large surpluses in milk production, the implications of the alternative policies are more sharply delineated. Assuming a permanent large reduction in milk demand, and future excess production, the choice of policies clearly will have much larger impacts than it would under the baseline demand scenario.

The reduced demand scenario is useful, not because it is a likely result of bST adoption, but because similar conditions (in terms of relative supply and demand) could prevail for a number of other reasons. For example, if bST results in greater average productivity increases than is here assumed, or if adoption rates are substantially higher, then supply excesses similar to those under the reduced demand scenario could result. This scenario thus can be viewed as a proxy for a number of supply or demand situations that could produce large surpluses of milk.

Figure B-13 shows the impact of reduced demand on milk production (given medium bST adoption) with alternative policies—fixed support price, trigger-adjusted support price, production quota, and a dairy termination program. Differences in the time path of milk production under the quota and the other policies are readily apparent. The quota results in a quick downward adjustment in dairy herd size necessary to avoid large government expenditures while maintaining milk price at the $10.60 support level. The dairy termination program (buyout occurs in 1992) adjusts herd size in a manner similar to the quota in 1992, but herd size and total milk production climb rapidly before declining again in 1998. The trigger policy results in an eventual but much delayed decline in milk production. The fixed support price policy, as expected, maintains the highest level of milk production of the alternative policies.

The implications of the alternative policies on milk price are likewise quite dramatic (see figure B-14). The fixed support and quota policies maintain a milk support price of $10.60. Figure B-14 shows that the all-milk price correspondingly is at the minimum level of $11.60 with these policies after bST is adopted (and the demand shift occurs). The trigger and dairy termination programs allow milk support price to adjust downward in the face of excess milk production. The trigger results in milk price declines to a minimum of $8.60 in 1997. The dairy termination program also allows milk price to fall to this level but with a delay of 1 year compared to the trigger policy. This is because the dairy termination program buyout occurs in 1992, avoiding the need for a reduction in milk support price prior to 1993.

Figure B-15 reiterates these impacts in terms of government milk purchases. It is significant to note that while the dairy termination program reduces milk purchases and expenditures quite successfully in 1992 (the year that liquidation occurs), milk production quickly bounces back and milk program purchases are not much lower than those associated with the trigger policy alone. From 1995 to 1998, purchases under the trigger policy are actually less than they are under the dairy termination program.

Impacts on Other Agricultural Sectors

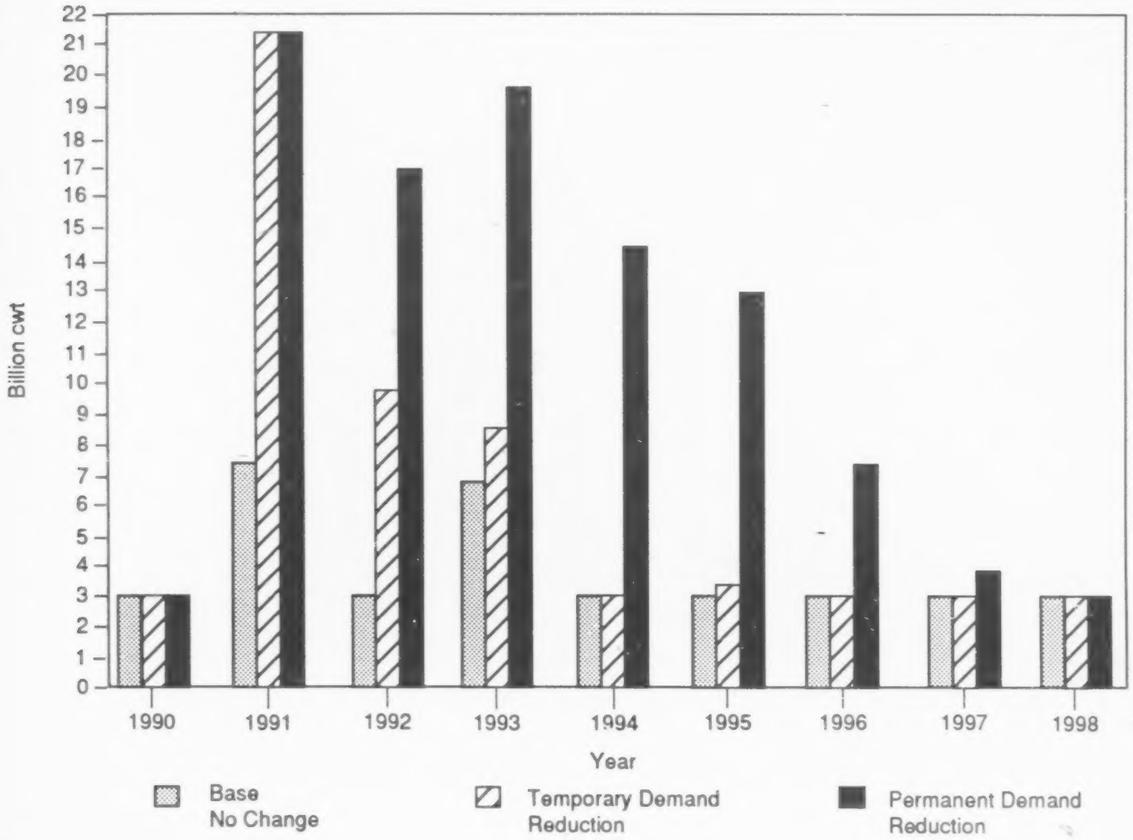
The adoption of bST appears to have relatively minor impacts on agricultural sectors outside of dairy. Table B-1 summarizes agricultural commodity prices over the period 1995-1998 for the fixed support price, trigger-adjusted support price, and quota policies with and without bST adoption (medium level).

The adoption of bST does create a marginal increase in demand for feed in the dairy industry. However, the net effect, when all markets adjust, is extremely small. Among all crops, impacts on the all hay price are largest with bST adoption; average hay prices increase by $1.25 to $2.50/ton depending on the policy scenario.

Impacts in the livestock sectors are limited mostly to cattle, and average price effects are minute. Interestingly, how bST adoption impacts yearling, calf, and cow prices depends on the policy scenario. This indicates that dairy policy can affect the timing and magnitude of changes in the dairy herd.

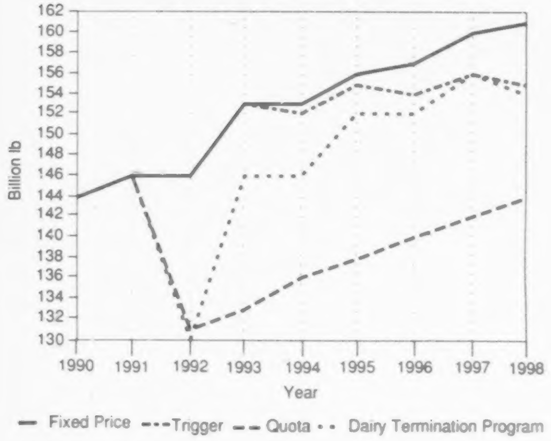
The impact of a dairy termination program on livestock prices is of particular interest. Figure B-16 shows the dynamic paths of yearling cattle price for alternative dairy policies. (Figure B-16 also assumes a permanent milk demand decrease in conjunction with bST adoption.)

Figure B-12—Projected Government Milk Purchases With bST Adoption Under Alternative Milk Demands



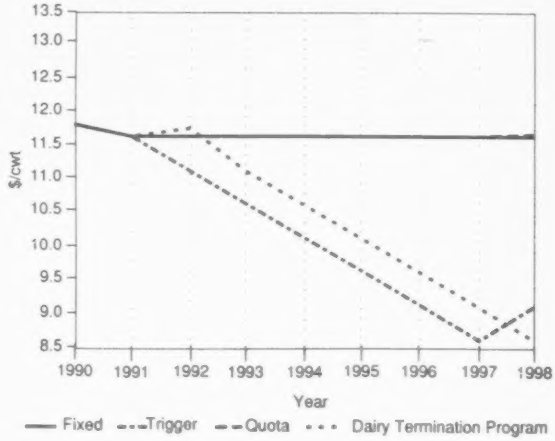
SOURCE: Office of Technology Assessment, 1991.

Figure B-13—Projected Milk Production With Permanently Reduced Milk Demand Under Alternative Dairy Policies



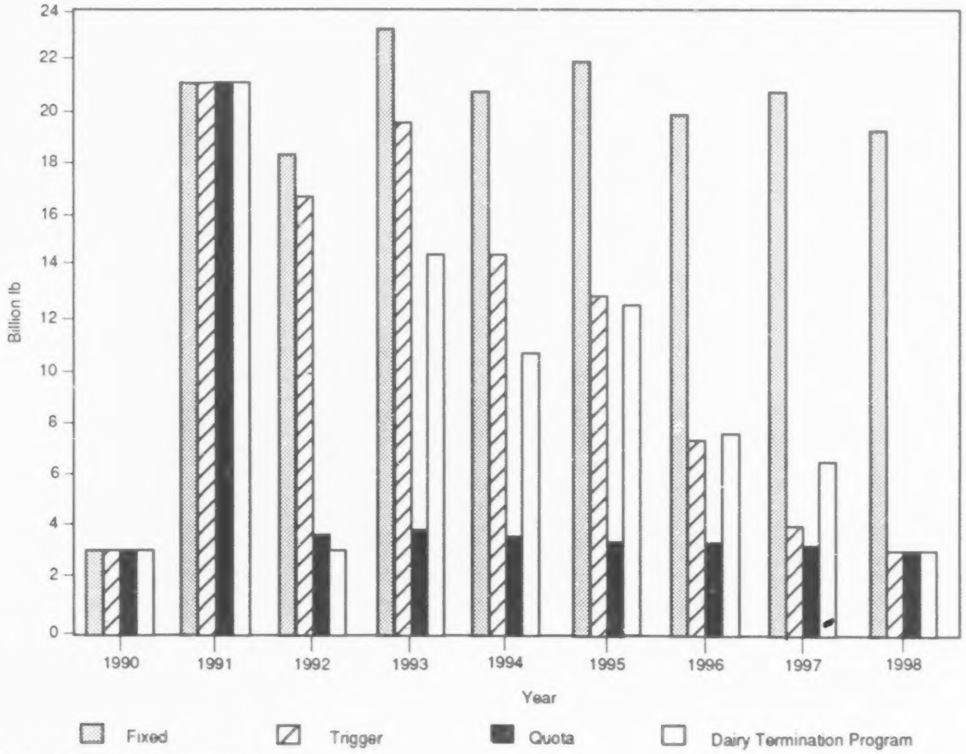
SOURCE: Office of Technology Assessment, 1991.

Figure B-14—Projected All Milk Price With Permanently Reduced Milk Demand Under Alternative Dairy Policies



SOURCE: Office of Technology Assessment, 1991.

Figure B-15—Projected Government Milk Purchases With Permanently Reduced Milk Demand Under Alternative Dairy Policies



SOURCE: Office of Technology Assessment, 1991.

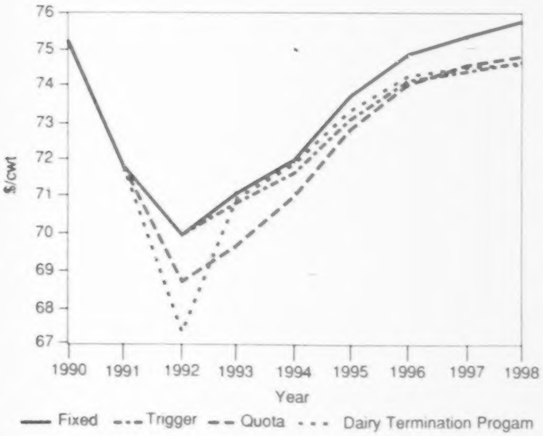
Table B-1—Impacts of bST Adoption on Other Agricultural Sectors, 1995-98

	Policy scenarios					
	Fixed price support		Trigger price		Quota	
Commodity (units)	No bST	bST	No bST	bST	No bST	bST
Corn ($/bu)	2.85	2.86	2.85	2.86	2.85	2.86
Grain sorghum ($/bu)	2.54	2.54	2.54	2.54	2.54	2.54
Barley ($/bu)	2.60	2.61	2.60	2.61	2.60	2.61
Oats ($/bu)	1.39	1.40	1.39	1.40	1.39	1.39
Wheat ($/bu)	3.09	3.09	3.09	3.09	3.09	3.09
Soybeans ($/bu)	6.46	6.47	6.46	6.46	6.46	6.46
Cotton ($/lb)	0.86	0.86	0.86	0.86	0.86	0.86
All hay ($/ton)	103.06	105.55	102.95	104.64	102.77	104.03
Yearling cattle ($/cwt)	74.87	74.94	74.92	74.79	75.08	74.97
Calf ($/cwt)	81.84	82.01	81.93	81.84	82.16	82.06
Cows ($/cwt)	56.97	57.11	57.05	56.84	57.33	57.14
Hogs ($/cwt)	51.08	51.09	51.06	51.11	51.01	51.04
Broilers (¢/lb)	61.38	61.45	61.43	61.43	61.46	61.47
Turkeys (¢/lb)	69.32	69.38	69.41	69.29	69.55	69.49
Eggs (¢/dozen)	81.15	81.20	81.14	81.18	81.14	81.16
Lamb ($/cwt)	91.46	91.63	91.45	91.62	91.41	91.51

KEY: bu = bushel; cwt = hundredweight (100 pounds); lb = pound.

SOURCE: Office of Technology Assessment, 1991.

Figure B-16—Projected Yearling Cattle Price With Permanently Reduced Milk Demand Under Alternative Dairy Policies



SOURCE: Office of Technology Assessment, 1991.

Annual yearling cattle prices are about $4.35 per cwt lower in 1992 as a result of the dairy termination program (compared to the trigger policy). Cow prices in 1992 are over $6.00 per cwt lower with the dairy termination program compared to the trigger policy. The quota policy affects cattle price in much the same way as the dairy termination program; its impacts are slightly less in magnitude in 1992, the year that the quota is imposed, but prices are slightly lower under the quota relative to the dairy termination program for several more years.

Appendix B References

1. Peel, D.S., "A Dynamic Econometric-Simulation Model of the U.S. Livestock Industry," Ph.D. dissertation, Department of Agricultural Economics, University of Illinois, 1989.
2. Taylor, C.R., "A Description of AGSIM, an Econometric-Simulation Model of Regional Crop and National Livestock Production in the United States," staff paper ES89-1, Department of Agricultural Economics and Rural Sociology, Auburn University, Auburn, Alabama, January 1989.
3. Taylor, C.R., "AGSIM User's Manual, Version 89.5," staff paper ES89-11, Department of Agricultural Economics and Rural Sociology, Auburn University, Auburn, AL, October 1989.

Appendix C

Detailed Farm Level Impacts of bovine Somatotropin and Other Emerging Technologies Under Alternative Policy and Demand Scenarios

The farm level impacts in chapter 5 were determined by a Monte Carlo simulation model known as the Farm Level Income Tax and Policy Simulation Model (FLIPSIM) developed by Richardson and Nixon (4) at Texas A&M University. The model is capable of simulating representative dairy farms in different regions of the United States under alternative policy and technology assumptions.[1]

Analyzing the consequences of alternative technologies on the economic viability of a representative farm involves several steps. First, data for the representative dairy farm that is using existing technologies must be developed. Second, modifications to the basic dairy farm's input/output coefficients must be made for each technology change to be analyzed. For bST, this is done by annually changing the milk per cow and the lactating cow ration and by increasing variable costs per cow to reflect bST purchases. The result is a new representative farm that has adopted bST. Third, projections for milk prices, feed prices, cattle prices, annual percentage changes in herd size, and macroeconomic variables (interest and inflation rates) for the policy/technology scenario being analyzed are merged with the farm's data. Projections of regionalized milk prices and feed prices are provided by the LIVESIM model (described in app. B), and macroeconomic variables are developed by the COMGEM/AG-GEM model (3).

Representative Dairy Farms

The regions for analysis are the Lake States, Northeast, Southeast, and Southwest. Two different-size dairy farms in each region—moderate and large farms—are considered. In the Lake States, the representative moderate-size farm owns 52 cows, and the large farm owns 125 cows; both farms own 185 acres of cropland and farmstead, with 155 acres devoted to the production of dairy feed (see table C-1). These farms are most representative of dairy farms in Minnesota. In the Northeast, the representative moderate-size farm owns 52 cows, and the large farm owns 200 cows. The moderate-size Northeast farm devotes 140 acres to the production of hay, corn silage, haylage, oats, corn, and pasture. The large Northeastern farm has 450 acres of hay, corn silage, haylage, oats, and corn, and 50 acres of pasture. The moderate-size farm is most representative of Pennsylvania dairy farms and the large farm represents New York dairy farms.

The moderate and large Southwestern dairy farms, respectively, own 350 and 1,500 milk cows (see table C-1) and only 25 acres of land. The two farms are representative of dairy herds in California and Arizona. The moderate-size Southeastern dairy farm has 200 cows and 388 acres and is most representative of farms in Georgia. The Georgia farm has 305 acres devoted to coastal hay and sorghum silage production and 50 acres devoted to pasture. The large Southeastern dairy has 1,500 cows and owns 873 acres, which are largely (750 acres) devoted to pasture. The large Southeastern farm is most representative of large dairies in Florida.

The initial debt-to-asset ratio was assumed to be 40 percent for all of the farms. All land, machinery, and livestock had 40-percent debt at the beginning of 1989 (see table C-1). This level of debt represents a moderate initial debt level. Each of the eight representative farms were simulated over the 1989 to 1998 planning horizon for alternative assumptions about the dairy farm program and the adoption of bST.

Technology Scenarios

The economic consequences of bST adoption were analyzed assuming bST was introduced in 1991, and the farm either adopted it in 1991 or did not adopt bST throughout the planning horizon. Initial milk production per cow was trended up at 1.5 percent per year in the base situation without bST (see table C-2). For the bST adoption scenarios, annual milk production per cow with bST was increased by 1,320 pounds each year from 1991 to 1998. This increase in milk per cow due to the adoption of bST assumes lactating cows are treated for 150 days during each lactation. All cows in the herd were assumed to be treated at an annual cost of $45 per cow.

The quantity of feed required for bST-treated cows increased marginally due to the increased milk production per cow. A linear program (LP) model in FLIPSIM was used to estimate a balanced dairy ration for the higher producing dairy herd. Research by Chalupa and Galligan (1) indicates that the nutritional requirements for bST-treated cows are the same as they are for naturally high

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[1] This appendix is based on the OTA commissioned background paper "Farm Level Impacts of bovine Somatotropin Introduction and Adoption Under Alternative Farm Policies" prepared by James W. Richardson, Texas A&M University. It is available through the National Technical Information Service.

Table C-1—Characteristics of Representative Moderate-Size and Large Dairy Farms in the Lake States, Northeast, Southwest, and Southeast

	Lake States		Northeast		Southwest		Southeast	
	Moderate	Large	Moderate	Large	Moderate	Large	Moderate	Large
Number of dairy cattle:								
Cows	52	125	52	200	350	1,500	200	1,500
Calves	21	48	20	75	130	495	75	432
Heifers	25	57	23	88	152	612	88	503
Bulls	0	0	0	0	7	25	0	25
Calves born	48	113	47	178	326	1,388	176	1,268
Assets ($1,000):								
Land	133.1	295.0	274.2	640.1	117.9	491.8	812.9	4,591.1
Buildings and machinery	262.8	482.6	260.8	503.0	467.3	1,080.8	487.0	1,139.2
Cattle	68.6	161.6	73.0	251.5	511.4	2,284.9	269.4	1,992.3
Total	469.5	940.2	608.0	1,394.6	1,096.6	3,857.5	1,569.3	7,722.6
Off-farm salary ($1,000)	9.8	0	9.8	0	0	0	0	0
Minimum family living ($1,000)	19.8	24.8	19.8	30.9	43.3	61.9	30.9	61.9
Labor costs ($1,000)	12.7	37.3	11.3	70.0	115.8	444.2	62.8	488.1
Milk/cow (cwt)	168.5	168.5	179.4	178.3	185.9	196.9	153.4	153.1

SOURCE: Office of Technology Assessment, 1991.

producing cows. Thus, it was not necessary to change the input/output coefficients in the ration-balancing LP—the increased milk production per cow caused the LP to feed the cow more protein, energy, and forage. In general, the ration for bST cows contained 7 to 10 percent more forage, 9 to 12 percent more grain, and 10 to 13 percent more soybean meal (or whole cottonseed) than the ration for control cows.

The new values for average annual milk per cow and bST costs were used to modify initial farm variables to account for bST adoption. All other variables for the representative dairy farms were assumed to remain constant at pre-bST levels. Of 16 representative farms, 8 adopt bST in 1991, and 8 do not adopt bST. The 16 farms were simulated under alternative dairy policy scenarios to quantify the interaction between technology adoption and farm programs.

Farm Program and Milk Demand Scenarios

Four farm programs were selected for the analysis: trigger price, fixed price support, production quota, and dairy termination program. Each of the policies was analyzed with a commodity-specific livestock simulation model, LIVESIM (discussed in app. B), under the assumption that the 1985 farm program for crops would continue through 1998 (2). The LIVESIM analyses of these four dairy policies were done for a no-bST scenario and for a scenario with a medium rate of adoption beginning in 1991. Three different milk-demand scenarios were analyzed to incorporate the possibility of milk demand changing in response to bST introduction.

The trigger-price dairy policy is similar to policy from 1985 to 1990 with the milk-support price decreasing 50 cents per hundredweight (cwt) each year that the Commodity Credit Corporation (CCC) milk purchases are expected to exceed 5 billion pounds of milk equivalent. The support price is increased 50 cents per cwt if CCC purchases of milk are expected to fall short of 2.5 billion pounds. This policy is also similar to the producer assessment option in the 1990 farm bill because the assessment will effectively trigger reductions in producer returns as milk price declines. The fixed support policy assumes that the dairy support price is held constant for all years of the planning horizon. The production-quota policy calls for the continuation of the trigger-price policy with provisions for a quota to be imposed if CCC milk purchases exceeded 7.0 billion pounds of milk equivalent. Similarly, the dairy termination program would continue the trigger-price policy but permit a one-time dairy termination if CCC milk equivalent purchases exceed 15.0 billion pounds in 1 year. The dairy termination program is analyzed only for the large demand decrease scenario, as this is the only demand situation that triggers the termination.

The three milk-demand scenarios respectively assume constant demand, a slight decrease in demand, and a significant decrease in demand after the introduction of bST. The small demand reduction scenario assumes that milk demand will decrease 10 percent in 1991, 5 percent in 1992 (i.e., demand increases from 1991 to 1992), and 2.5 percent each year from 1993 to 1998. The large demand reduction scenario assumes that milk demand is 10 percent lower than it currently is in each year from 1991 to 1998. The trigger price, fixed price support, and

Table C-2—Average Annual Production of Milk/Cow for Moderate-Size Representative Dairy Farms, in Selected Regions, With and Without bST, 1989-98 (cwt/year)

	Lake States		Northeast		Southwest		Southeast	
Years	No bST[a]	bST[b]	No bST	bST	No bST	bST	No bST	bST
1989	168.5	168.5	179.4	179.4	185.9	185.9	153.4	153.4
1990	171.0	171.0	182.0	182.0	188.7	188.7	155.7	155.7
1991	173.6	186.8	184.8	198.0	191.5	204.7	158.1	171.3
1992	176.2	189.4	187.5	200.7	194.4	207.6	160.4	173.6
1993	178.8	192.0	190.4	203.6	197.3	210.5	162.8	176.0
1994	181.5	194.7	193.2	206.4	200.2	213.4	165.3	178.5
1995	184.2	197.4	196.1	209.3	203.2	216.4	167.8	181.0
1996	186.9	200.1	199.1	212.3	206.3	219.5	170.3	183.5
1997	189.8	203.0	202.0	215.2	209.4	222.6	172.8	186.0
1998	192.6	205.8	205.1	218.3	212.5	225.7	175.4	188.6

[a] Output per cow increases 1.5 percent per year without bST.

[b] bST, introduced in 1991, increases output per cow 1,320 lbs. per year.

SOURCE: Office of Technology Assessment, 1991.

quota policies were analyzed with and without bST assuming no change in milk demand. The trigger price policy was analyzed for the small decrease and large decrease demand scenarios because this policy represents current policy under the 1990 farm bill. The dairy termination program was analyzed for the large decrease in milk demand and results were compared to those of the trigger price policy under this demand reduction.

The adoption rates for bST in LIVESIM differ by region and follow a sigmoid adoption function (see app. A). It is projected that 43.6 percent of the dairy farms in the Lake States would adopt bST by 1998. In the Northeast, 39.9 percent of farms would adopt by 1998; in the Pacific region, about 63 percent of farms would adopt bST by 1998; and 36.7 percent of those in the Southeast would adopt by 1998. Adoption by 1998 in the remaining regions ranged from 29.7 to 42.9 percent.

For the FLIPSIM analyses, cattle and feed price projections from LIVESIM were regionalized using simple regression relationships between National- and State-level prices. Milk-price projections were region specific so no adjustment was necessary. The LIVESIM projected annual changes in the dairy herd that were region specific; these projections were used to adjust the number of cows on the representative farms. It was assumed that each farm's herd size would change annually (1990 to 1998) proportional to the annual percentage change in the respective region's total number of dairy cows. Thus, the number of cows milked on the representative farms fluctuated annually with expected net returns in the region.

Results

The detailed results of simulating the representative farms with and without bST are summarized in this section. Simulation results for various scenarios are presented in terms of three probabilities and means for the probability distributions of four key output variables. The variables used for evaluating the economic impacts of the alternative scenarios are defined as follows:

- *Probability of Survival*—chance that the individual farm will remain solvent through 1998, i.e., maintain more than 10-percent equity in the farm.
- *Probability of Success*—chance that the individual farm will earn a 5-percent or greater after-tax return on initial equity.
- *Probability of Increasing Equity*—chance that the individual farm will increase its net worth in real 1989 dollars over the planning horizon.
- *Net Present Value*—present value of annual changes in net worth plus family consumption minus off-farm income.
- *Present Value of Ending Net Worth (PVENW)*—ending net worth for 1998 discounted to 1989 dollars, assuming a 5-percent discount rate.
- *PVENW as a Percent of Beginning Net Worth*—PVENW divided by initial net worth indicates whether the farm increased (or decreased) net worth in real dollars.
- *Average Annual Net Cash Farm Income*—total cash farm receipts minus total cash expenses excluding family living, income taxes, and principle payments.

Economic Payoffs to bST Adoption for Alternative Farm Policies

Tables C-3 through C-6 summarize the simulation results for representative dairy farms in the Lake States, Northeast, Southwest, and Southeast, respectively, assuming bST is introduced in 1991. Results are reported for the bST adopter and nonadopter. The adopter is assumed to use bST on all lactating cows beginning in 1991. The nonadopter does not adopt bST over the 1989 to 1998 planning horizon. The economic payoffs for bST adoption are reported for three different farm policies (see table C-6).

Table C-3—Impacts of bST Adoption on the Economic Viability of Representative Lake State Dairy Farms Under Alternative Dairy Policies, Assuming No Change in Milk Demand Due to bST, 1989-98

	Policy scenario					
	Trigger price		Fixed price support		Quota	
	Non-adopter	bST adopter	Non-adopter	bST adopter	Non-adopter	bST adopter
52-cow farm:						
Probability of survival (percent)	58.0	74.0	73.0	89.0	41.0	52.0
Probability of success (percent)	58.0	74.0	73.0	89.0	41.0	52.0
Probability of increasing equity (percent)	0.0	0.0	0.0	1.0	0.0	0.0
Net present value ($1,000)	25.2	67.6	65.0	105.6	–15.1	9.8
Present value of ending net worth ($1,000)	44.3	81.2	75.9	112.8	7.4	27.8
Present value of ending net worth as a percent of beginning net worth (percent)	15.6	28.5	27.1	39.7	2.6	9.8
Average annual net cash farm income ($1,000)	–2.0	1.9	1.7	5.8	–4.7	–2.3
125-cow farm:						
Probability of survival (percent)	95.0	99.0	99.0	100.0	85.0	92.0
Probability of success (percent)	90.0	95.0	95.0	98.0	67.0	78.0
Probability of increasing equity (percent)	8.0	12.0	11.0	18.0	2.0	3.0
Net present value ($1,000)	194.8	271.9	265.0	340.1	68.7	127.7
Present value of ending net worth ($1,000)	329.1	396.4	386.9	451.5	211.9	263.7
Present value of ending net worth as a percent of beginning net worth (percent)	57.1	68.7	67.1	78.3	36.7	45.7
Average annual net cash farm income ($1,000)	23.1	33.4	32.1	43.0	11.2	18.2

SOURCE: Office of Technology Assessment, 1991.

Table C-4—Impacts of bST Adoption on the Economic Viability of Representative Northeast Dairy Farms Under Alternative Dairy Policies, Assuming No Change in Milk Demand Due to bST, 1989-98

	Policy scenario					
	Trigger price		Fixed price support		Quota	
	Non-adopter	bST adopter	Non-adopter	bST adopter	Non-adopter	bST adopter
52-cow farm:						
Probability of survival (percent)	100.0	100.0	100.0	99.0	99.0	99.0
Probability of success (percent)	100.0	100.0	100.0	100.0	96.0	97.0
Probability of increasing equity (percent)	3.0	3.0	3.0	8.0	0.0	0.0
Net present value ($1,000)	232.3	253.9	254.6	277.5	110.8	117.0
Present value of ending net worth ($1,000)	268.3	286.4	285.6	303.7	169.0	174.7
Present value of ending net worth as a percent of beginning net worth (percent)	72.4	77.2	77.0	81.9	45.6	47.1
Average annual net cash farm income ($1,000)	14.5	17.9	17.8	21.4	–1.9	–0.9
200-cow farm:						
Probability of survival (percent)	100.0	100.0	100.0	100.0	88.0	91.0
Probability of success (percent)	99.0	100.0	100.0	100.0	64.0	72.0
Probability of increasing equity (percent)	43.0	53.0	50.0	66.0	1.0	3.0
Net present value ($1,000)	616.7	717.6	705.7	812.3	102.8	166.6
Present value of ending net worth ($1,000)	776.8	855.4	842.0	922.0	360.0	415.9
Present value of ending net worth as a percent of beginning net worth (percent)	92.3	101.7	100.1	109.6	42.8	49.4
Average annual net cash farm income ($1,000)	56.2	82.0	79.6	96.2	–1.5	7.3

SOURCE: Office of Technology Assessment, 1991.

Table C-5—Impacts of bST Adoption on the Economic Viability of Representative Southwest Dairy Farms Under Alternative Dairy Policies, Assuming No Change in Milk Demand Due to bST, 1989-98

	Policy scenario					
	Trigger price		Fixed price support		Quota	
	Non-adopter	bST adopter	Non-adopter	bST adopter	Non-adopter	bST adopter
350-cow farm:						
Probability of survival (percent)	95.0	97.0	99.0	99.0	95.0	97.0
Probability of success (percent)	95.0	97.0	99.0	99.0	95.0	97.0
Probability of increasing equity (percent)	60.0	79.0	81.0	89.0	40.0	56.0
Net present value ($1,000)	739.7	885.2	903.5	1,040.0	622.9	715.4
Present value of ending net worth ($1,000)	701.2	820.7	827.1	939.5	587.1	664.1
Present value of ending net worth as a percent of beginning net worth (percent)	109.5	128.1	129.1	146.7	91.7	103.7
Average annual net cash farm income ($1,000)	109.6	136.1	137.2	163.8	97.1	115.4
1,500-cow farm:						
Probability of survival (percent)	100.0	100.0	100.0	100.0	100.0	100.0
Probability of success (percent)	100.0	100.0	100.0	100.0	100.0	100.0
Probability of increasing equity (percent)	100.0	100.0	100.0	100.0	98.0	99.0
Net present value ($1,000)	4,062.8	4,548.7	4,633.6	5,148.7	3,532.5	3,853.0
Present value of ending net worth ($1,000)	4,323.0	4,751.1	4,795.4	5,249.3	3,808.5	4,091.2
Present value of ending net worth as a percent of beginning net worth (percent)	194.5	213.7	215.7	236.2	171.3	184.1
Average annual net cash farm income ($1,000)	713.9	804.4	808.5	900.2	604.8	666.0

SOURCE: Office of Technology Assessment, 1991.

Table C-6—Impacts of bST Adoption on the Economic Viability of Representative Southeast Dairy Farms Under Alternative Dairy Policies, Assuming No Change in Milk Demand Due to bST, 1989-98

	Policy scenario					
	Trigger prica		Fixed price support		Quota	
	Non-adopter	bST adopter	Non-adopter	bST adopter	Non-adopter	bST adopter
200-cow farm:						
Probability of survival (percent)	100.0	100.0	100.0	100.0	100.0	100.0
Probability of success (percent)	100.0	100.0	100.0	100.0	93.0	99.0
Probability of increasing equity (percent)	13.0	24.0	23.0	44.0	5.0	9.0
Net present value ($1,000)	453.3	601.5	559.9	712.0	333.3	446.7
Present value of ending net worth ($1,000)	727.9	854.3	815.3	940.5	615.2	712.8
Present value of ending net worth as a percent of beginning net worth (percent)	75.6	88.7	84.7	97.7	63.9	74.0
Average annual net cash farm income ($1,000)	17.3	39.2	32.5	55.3	2.6	19.8
1,500-cow farm:						
Probability of survival (percent)	100.0	100.0	100.0	100.0	100.0	100.0
Probability of success (percent)	100.0	100.0	100.0	100.0	100.0	100.0
Probability of increasing equity (percent)	88.0	99.0	97.0	100.0	75.0	91.0
Net present value ($1,000)	4,964.9	6,165.7	5,757.5	7,000.8	4,113.7	5,062.2
Present value of ending net worth ($1,000)	5,901.3	6,712.4	6,415.4	7,252.3	5,261.1	5,901.2
Present value of ending net worth as a percent of beginning net worth (percent)	129.4	147.2	140.7	159.0	115.4	129.4
Average annual net cash farm income ($1,000)	609.0	775.4	714.3	880.6	481.9	613.9

SOURCE: Office of Technology Assessment, 1991.

Trigger Price—Under the trigger-price program, the milk support price is decreased 50 cents per cwt each year the CCC purchases 5 billion pounds of milk equivalent. This option is similar to policy from 1985 to 1990 and to the assessment option in the 1990 farm bill—the assessment will effectively trigger reduction in producer returns as milk price declines.

The average annual economic payoffs from bST adoption (change in average annual net cash farm income due to adoption), given a trigger price dairy policy, ranges from $3,400 for a 52-cow Northeastern dairy to $166,400 for a 1,500-cow dairy in the Southeast. Average annual net cash farm income for the 52-cow Northeast dairy increases from $14,500 to $17,900 due to bST adoption (see table C-4). The 52-cow Lake States dairy experiences a slightly greater economic payoff from bST adoption ($3,900) as net cash farm income increases from -$2,000 to $1,900 (see table C-3). The greatest economic payoffs for bST adoption are earned by the 1,500-cow dairy farms in the Southwest and Southeast. In the Southwest, average annual net cash farm income increases $90,500 ($713,900 to $804,400) and in the Southeast, the increase is $166,400 ($609,000 to $775,400) (see tables C-5 and C-6). Absolute increases in real net worth are also greatest for these dairies; however, the greatest percentage increases are observed for the dairy farms in the Lake States, and for the moderate-size dairy in the Southwest.

Increases in average annual net cash farm income due to adopting bST lead to greater accumulation (or slower decline) in net worth which, in turn, leads to greater after-tax net present values for bST adopters. The 52-cow Lake States dairy producer who adopts bST has a $42,400 greater net present value than the nonadopter, and $36,900 greater present value of ending net worth (see table C-3). This pattern of greater net worth and net present values due to bST adoption is observed for all eight representative farms.

Increases in average annual net cash farm income due to bST adoption also leads to improved probabilities of survival, success, and to increases in real equity. Probability of survival increases from 58 to 74 percent for the 52-cow Lake States dairy as a result of adopting bST (see table C-3). Adopting bST increases the probability of increasing real net worth (equity) for five of the eight representative dairy farms. The three exceptions experienced no change in the probability of increasing real equity due to adopting bST.

Fixed Price Support—Maintaining the milk price support at the 1989 value through the 1989-1998 planning horizon results in higher milk prices and greater average annual net cash farm incomes than the trigger price policy (see tables C-3 to C-6). Economic payoffs from bST adoption are only slightly greater under the fixed price-support policy than under the trigger price policy for six of the eight farms. For example, the economic payoff for the 125-cow Lake States dairy increases only $600 from $10,300 to $10,900 due to the policy change (see table C-3). (The two dairy farms that experience lower economic payoffs (Southwest 350-cow dairy and 1,500-cow Southeast dairy) experience very small reductions in their economic payoffs from bST adoption, $700 and $100, respectively (see tables C-5 and C-6).) These results suggest that the economic incentive to adopt bST would not be greatly increased by increasing the price of milk, i.e., freezing the milk support price at its 1989 level. Maintaining a fixed support price would result in a greater probability of survival, success, and increasing real equity (i.e., increasing a farm's economic viability) than observed for the trigger price scenario. For a 52-cow Lake States dairy farm that adopts bST, probability of survival increases from 74 to 89 percent, and for the nonadopter, the probability increases from 58 to 73 percent (see table C-3).

Production Quota—A quota that reduces the number of dairy cows to maintain milk prices at levels comparable to the fixed price support policy was analyzed. Results of the analyses reveal that a quota reduces average annual net cash farm incomes for adopters and nonadopters, relative to the other two dairy policies (see tables C-3 to C-6). Relative to the trigger price, the quota reduces net cash farm income about $15,000 per year for the 125-cow Lake States dairy farm that adopts bST, and about $11,900 for the nonadopter. The large Southeastern dairy that adopts bST experiences a $161,500 decrease in average annual net cash farm income under a switch from the trigger price to the quota policy (see table C-6). Such dramatic decreases in net cash farm income lead to lower probabilities of increasing real net worth for all eight farms, and lower the probability of survival for five farms.

The economic payoffs from adopting bST while a quota policy is in effect are positive for all eight farms (see tables C3-C6). However, the absolute economic payoffs are less than under the trigger price policy. The large Southeastern dairy farm experiences an average annual economic payoff from bST of $132,000 under the quota, compared to $166,400 under the trigger price policy (see table C-6). Similarly, the 52-cow Lake States dairy experiences a decrease in bST economic payoffs from $3,900 to $2,400 due to the policy scenario change (see table C-3).

The primary reason that the farms perform less favorably under the quota than the other two policies is that the total milk sold is reduced while fixed costs remain the same. Fewer cows and pounds of milk are available to spread out the fixed costs associated with the fixed plant size. If the dairy farms were able to utilize the resulting excess capacity for other purposes, the decrease in net cash farm income, net worth, and probabilities of survival and success would not be as great. However, the specialized facilities associated with modern dairy farming are not suitable for other enterprises.

Summary—Simulation results for representative dairy farms indicate that bST adopters enjoy a greater average annual net cash farm income than nonadopters across three different types of farm policies. In addition to increasing net cash farm income, bST adoption leads to greater real ending net worth, after-tax net present value, and probabilities of survival and success. Economic payoffs to bST adopters are greater for larger farms than for smaller farms. The increased net return for larger farms may accelerate the growth in average herd size as producers seek to reduce fixed costs per cow, and take greater advantage of high-level management practices associated with bST adoption.

The absolute economic payoff from bST adoption is about the same under a trigger price dairy policy and a fixed support price policy (see table C-7). Increasing the price of milk by maintaining the milk support price at its 1989 level does not greatly increase the economic incentive to adopt bST. On the other hand, the economic incentive to adopt bST is significantly lower if a production quota is in effect. All but one of the eight representative farms experienced a 20- to 40-percent decrease in the economic payoff to adopt bST under a quota. The exception (52-cow Northeast dairy) experienced a 70-percent decrease in the economic payoff associated with bST adoption. These results suggest that the rate of bST adoption would be slowed by imposing a strict production quota rather than a trigger price policy.

Table C-7—Comparison of Average Annual Economic Payoffs From bST Adoption for Eight Representative Dairy Farms Under Three Alternative Dairy Policies, Assuming No Change in Milk Demand, 1989-98[a] (in $1,000)

	Policy scenario		
Region/size	Trigger price	Fixed support	Quota
Lake States:			
Moderate	3.9	4.1	2.4
Large	10.3	10.9	7.0
Northeast:			
Moderate	3.4	3.6	1.0
Large	15.8	16.6	8.8
Southwest:			
Moderate	26.5	26.6	18.3
Large	90.5	91.7	61.2
Southeast:			
Moderate	21.9	22.8	17.2
Large	166.4	166.3	132.0

[a] Economic payoffs from bST are the average annual change in net cash farm income between a nonadopter and a bST adopter over the 1989-98 planning horizon. The payoff is net of the cost of bST, the added transportation costs for milk, and the additional feed.

SOURCE: Office of Technology Assessment, 1991.

Economic Payoffs to bST Adoption for Alternative Milk Demands

The introduction of bST may contribute to a change in the demand for milk and milk products, depending on the perception of consumers. To quantify the impacts of milk demand changes on the economic incentives to adopt bST, the eight representative dairy farms were simulated under three alternative milk demand scenarios, with a trigger price policy. Tables C-8 to C-11 summarize the simulation results for the following changes in milk demand: no change, small decrease, and large decrease. For the no-change scenario, milk demand was assumed to be the same as under the no-bST scenario. A small decrease in milk demand is defined as a 10-percent decrease in 1991, a 5-percent decrease in 1992 (i.e., demand increases from 1991 to 1992), and a 2.5-percent decrease from 1993 to 1998. The large milk demand decrease involves a 10-percent decrease in demand persisting from 1991 to 1998.

Decreasing the demand for milk reduces the economic payoffs associated with bST adoption for all eight representative dairy farms (see tables C-8 to C-12). This result is observed for both small and large decreases in milk demand. For example, the economic payoff for bST adoption is $10,300 for the 125-cow dairy in the Lake States if there is no decrease in milk demand (see table C-12). If demand decreases slightly, the economic payoff falls to $9,200, and if the demand decrease is large, the economic payoff declines to $6,900 (see table C-12). Thus, the incentive to adopt and the rate of adoption would be reduced if milk demand declines due to consumers' reaction to bST.

The probabilities of survival and economic success are reduced as well by decreases in milk demand. These probabilities decline as lower milk prices lead to lower net cash farm incomes, net worths, and net present values. Examining the 350-cow dairy in the Southwest indicates that for the bST adopter, the probability of survival declines slightly from 97 to 94 percent if there is a small decline in milk demand (see table C-10). If the milk demand decrease is large, this farm's probability of survival falls to 69 percent. Because the economic payoff for bST adoption is positive (see table C-12), those producers who adopt bST will experience greater probabilities of survival and economic success than nonadopters.

The most significant result for the demand-change scenarios is the dramatic reduction in the economic viability of dairy farms (probabilities of survival, success, and of increasing real net worth) associated with a large decrease in milk demand (tables C-9 to C-12). All of the regions are affected by the lower milk demand, given a trigger price dairy policy. If a large decrease in milk demand is experienced, a dairy termination program

Table C-8—Effects of Milk Demand Changes on the Economic Viability of Representative Dairy Farms in the Lake States Who Adopt and Fail To Adopt bST, Assuming a Trigger Price Dairy Policy, 1989-98

	Demand scenario					
	No change in milk demand		Small demand reduction		Large demand reduction	
	Non-adopter	bST adopter	Non-adopter	bST adopter	Non-adopter	bST adopter
52-cow farm:						
Probability of survival (percent)	58.0	74.0	40.0	48.0	13.0	24.0
Probability of success (percent)	58.0	74.0	40.0	48.0	13.0	24.0
Probability of increasing equity (percent)	0.0	0.0	0.0	0.0	0.0	0.0
Net present value ($1,000)	25.2	67.6	–21.8	4.7	–85.5	–63.4
Present value of ending net worth ($1,000)	44.3	81.2	7.5	27.6	–47.9	–32.2
Present value of ending net worth as a percent of beginning net worth (percent)	15.6	28.6	2.6	9.7	–16.9	–11.3
Average annual net cash farm income ($1,000)	–2.0	1.9	–6.8	–3.8	–12.1	–10.2
125-cow farm:						
Probability of survival (percent)	95.0	99.0	85.0	91.0	46.0	61.0
Probability of success (percent)	90.0	95.0	68.0	82.0	37.0	47.0
Probability of increasing equity (percent)	8.0	12.0	2.0	7.0	0.0	0.0
Net present value ($1,000)	194.8	271.9	78.3	150.6	–126.8	–48.6
Present value of ending net worth ($1,000)	329.1	396.4	227.6	290.9	33.3	102.6
Present value of ending net worth as a percent of beginning net worth (percent)	57.1	68.7	39.5	50.4	5.8	17.8
Average annual net cash farm income ($1,000)	23.1	33.4	8.7	17.9	–10.7	–3.8

SOURCE: Office of Technology Assessment, 1991.

Table C-9—Effects of Milk Demand Changes on the Economic Viability of Representative Dairy Farms in the Northeast Who Adopt and Fail To Adopt bST, Assuming a Trigger Price Dairy Policy, 1989-98

	Demand scenario					
	No change in reduction		Small demand reduction		Large demand reduction	
	Non-adopter	bST adopter	Non-adopter	bST adopter	Non-adopter	bST adopter
52-cow farm:						
Probability of survival (percent)	100.0	100.0	100.0	100.0	100.0	100.0
Probability of success (percent)	100.0	100.0	100.0	99.0	99.0	100.0
Probability of increasing equity (percent)	3.0	3.0	1.0	2.0	0.0	0.0
Net present value ($1,000)	232.3	253.9	199.1	218.4	149.8	167.6
Present value of ending net worth ($1,000)	268.3	286.4	241.0	258.3	194.1	210.0
Present value of ending net worth as a percent of beginning net worth (percent)	72.4	77.2	65.0	69.7	52.4	56.7
Average annual net cash farm income ($1,000)	14.5	17.9	9.7	12.8	2.3	5.0
200-cow farm:						
Probability of survival (percent)	100.0	100.0	100.0	100.0	98.0	99.0
Probability of success (percent)	99.0	100.0	98.0	99.0	91.0	94.0
Probability of increasing equity (percent)	43.0	53.0	26.0	45.0	9.0	17.0
Net present value ($1,000)	616.7	717.6	542.6	632.7	352.2	438.8
Present value of ending net worth ($1,000)	776.8	855.4	722.8	799.4	542.9	618.4
Present value of ending net worth as a percent of beginning net worth (percent)	92.3	101.7	85.9	95.0	64.5	73.5
Average annual net cash farm income ($1,000)	66.2	82.0	56.4	71.1	27.4	40.2

SOURCE: Office of Technology Assessment, 1991.

Table C-10—Effects of Milk Demand Changes on the Economic Viability of Representative Dairy Farms in the Southwest Who Adopt and Fail To Adopt bST, Assuming a Trigger Price Dairy Policy, 1989-98

	Demand scenario					
	No change in milk demand		Small demand reduction		Large demand reduction	
	Non-adopter	bST adopter	Non-adopter	bST adopter	Non-adopter	bST adopter
350-cow farm:						
Probability of survival (percent)	95.0	97.0	88.0	94.0	52.0	69.0
Probability of success (percent)	95.0	97.0	88.0	94.0	52.0	69.0
Probability of increasing equity (percent)	60.0	79.0	35.0	51.0	6.0	11.0
Net present value ($1,000)	739.7	885.2	506.5	655.9	70.2	233.2
Present value of ending net worth ($1,000)	701.2	820.7	508.3	630.9	98.9	236.5
Present value of ending net worth as a percent of beginning net worth (percent)	109.5	128.1	79.4	98.5	15.4	36.9
Average annual net cash farm income ($1,000)	109.6	136.1	70.5	94.7	17.6	34.7
1,500-cow farm:						
Probability of survival (percent)	100.0	100.0	100.0	100.0	98.0	100.0
Probability of success (percent)	100.0	100.0	100.0	100.0	96.0	98.0
Probability of increasing equity (percent)	100.0	100.0	96.0	98.0	53.0	70.0
Net present value ($1,000)	4,062.8	4,548.7	3,230.6	3,678.3	1,820.4	2,268.0
Present value of ending net worth ($1,000)	4,323.0	4,751.1	3,600.8	3,992.2	2,278.4	2,671.1
Present value of ending net worth as a percent of beginning net worth (percent)	194.5	213.7	162.0	179.6	102.5	120.2
Average annual net cash farm income ($1,000)	713.9	804.4	554.5	642.5	282.7	360.2

SOURCE: Office of Technology Assessment, 1991.

Table C-11—Effects of Milk Demand Changes on the Economic Viability of Representative Dairy Farms in the Southeast Who Adopt and Fail To Adopt bST, Assuming a Trigger Price Dairy Policy, 1989-98

	Demand scenario					
	No change in milk demand		Small demand reduction		Large demand reduction	
	Non-adopter	bST adopter	Non-adopter	bST adopter	Non-adopter	bST adopter
200-cow farm:						
Probability of survival (percent)	100.0	100.0	99.0	100.0	88.0	94.0
Probability of success (percent)	99.0	100.0	89.0	94.0	51.0	80.0
Probability of increasing equity (percent)	13.0	24.0	4.0	9.0	0.0	1.0
Net present value ($1,000)	453.3	601.5	259.9	400.4	8.0	147.2
Present value of ending net worth ($1,000)	727.9	854.3	562.1	685.6	321.5	444.2
Present value of ending net worth as a percent of beginning net worth (percent)	75.6	88.7	58.4	71.2	33.4	46.1
Average annual net cash farm income ($1,000)	17.3	39.2	-9.7	10.7	-42.7	-25.1
1,500-cow farm:						
Probability of survival (percent)	100.0	100.0	100.0	100.0	100.0	100.0
Probability of success (percent)	100.0	100.0	100.0	100.0	89.0	99.0
Probability of increasing equity (percent)	88.0	99.0	65.0	86.0	19.0	50.0
Net present value ($1,000)	4,964.9	6,165.7	3,139.9	4,032.3	1,689.1	2,562.2
Present value of ending net worth ($1,000)	5,901.3	6,712.4	5,001.4	5,772.3	3,633.2	4,390.7
Present value of ending net worth as a percent of beginning net worth (percent)	129.4	147.2	109.7	126.6	79.7	96.3
Average annual net cash farm income ($1,000)	609.0	775.4	453.8	615.2	200.2	343.8

SOURCE: Office of Technology Assessment, 1991.

Table C-12—Comparison of Average Annual Economic Payoffs From bST Adoption for Eight Representative Dairy Farms Under Alternative Milk Demand Scenarios, Assuming a Trigger Price Dairy Policy, 1989-98[a] (in $1,000)

		Demand reduction	
Region/size	No change	Small	Large
Lake States:			
Moderate	3.9	3.0	1.9
Large	10.3	9.2	6.9
Northeast:			
Moderate	3.4	3.1	2.7
Large	15.8	14.7	12.8
Southwest:			
Moderate	26.5	24.2	17.1
Large	90.5	88.0	77.5
Southeast:			
Moderate	21.9	20.4	17.6
Large	166.4	161.4	143.6

[a] Economic payoffs from bST are the average annual change in net cash farm income between a nonadopter and a bST adopter over the 1989-98 planning horizon. The payoff is net of the cost of bST, the added transportation costs for milk, and the additional feed.

SOURCE: Office of Technology Assessment, 1991.

Table C-13—Comparison of Average Annual Economic Payoffs From bST Adoption for Eight Representative Dairy Farms, Given a Large Reduction in Milk Demand, Assuming a Trigger Price and Dairy Termination Program, 1989-98[a] (in $1,000)

Region/size	Trigger price policy	Dairy termination program
Lake States:		
Moderate	1.9	4.1
Large	6.9	10.3
Northeast:		
Moderate	2.7	3.2
Large	12.8	15.3
Southwest:		
Moderate	17.1	25.4
Large	77.5	85.3
Southeast:		
Moderate	17.6	22.3
Large	143.6	172.7

[a] Economic payoffs from bST are the average annual change in net cash farm income between a nonadopter and a bST adopter over the 1989-98 planning horizon. The payoff is net of the cost of bST, the added transportation costs for milk, and the additional feed.

SOURCE: Office of Technology Assessment, 1991.

could be implemented (similar to the program in 1986) to bring production back into line with milk demand.

The LIVESIM model (app. B) analyzed a dairy termination program, given a large reduction in milk demand. The result was higher milk prices than under the trigger price policy, given the same demand scenario. If the dairy termination program is implemented in 1991 higher milk prices result from 1992 to 1998. Differences in milk prices between the dairy termination program and the trigger price policy declined from 50 cents per cwt in 1992 to less than 10 cents per cwt in 1998 as milk supply increased relative to milk demand.

The farm-level impacts of the dairy termination program are summarized in tables C-13 to C-17. The trigger price policy results assume the same milk demand (large demand reduction) and are used as a reference policy. The dairy termination program leads to higher probabilities of survival, success, and increasing equity than the trigger price policy for all eight representative dairy farms. The moderate-size farms had greater increases in probability of survival than the large farms from the dairy termination program.

As observed for the other policy and demand scenarios, bST adopters were more profitable than nonadopters. This result is summarized, in terms of the average annual economic payoffs for bST adoption, in table C-13. The economic payoffs for bST adoption are positive for the dairy termination program and they are greater for the dairy termination program than for the trigger price policy. For example, the economic payoffs for a moderate-size Lake States dairy that adopts bST are $1,900 for the trigger price policy and $4,100 for the dairy termination program. A large Lakes States dairy farm had an economic payoff of $6,900 for the trigger price and $10,300 for the dairy termination program (see table C-13). In the remaining three regions, the large farms gained more from bST adoption than the moderate-size farms; this differential was greater under the dairy termination program than under the trigger price policy (see table C-13). This reflects the higher milk prices under the dairy termination program. It also suggests that bST adoption would be accelerated even in the face of declining milk demand if a dairy termination program was introduced.

Appendix C References

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Table C-14—Effects of a Large Reduction in Milk Demand on Representative Lake States Dairy Farms Who Adopt and Fail To Adopt bST, Given a Trigger Price and a Dairy Termination Program, 1989-98

	Policy scenario			
	Trigger price policy		Dairy termination program	
	Non-adopter	bST adopter	Non-adopter	bST adopter
52-cow farm:				
Probability of survival (percent)	13.0	24.0	90.0	96.0
Probability of success (percent)	13.0	24.0	90.0	96.0
Probability of increasing equity (percent)	0.0	0.0	1.0	4.0
Net present value ($1,000)	-85.5	-63.4	111.9	146.9
Present value of ending net worth ($1,000)	-47.9	-32.2	117.2	147.5
Present value of ending net worth as a percent of beginning net worth (percent)	-16.9	-11.3	41.3	51.9
Average annual net cash farm income ($1,000)	-12.1	-10.2	3.3	7.4
125-cow farm:				
Probability of survival (percent)	46.0	61.0	99.0	100.0
Probability of success (percent)	37.0	47.0	97.0	99.0
Probability of increasing equity (percent)	0.0	0.0	20.0	31.0
Net present value ($1,000)	-126.8	-48.6	326.1	395.6
Present value of ending net worth ($1,000)	33.3	102.6	438.0	498.6
Present value of ending net worth as a percent of beginning net worth (percent)	5.8	17.8	76.0	86.5
Average annual net cash farm income ($1,000)	-10.7	-3.8	35.9	46.2

SOURCE: : Office of Technology Assessment, 1991.

Table C-15—Effects of a Large Reduction in Milk Demand on Representative Northeast Dairy Farms Who Adopt and Fail To Adopt bST, Given a Trigger Price and a Dairy Termination Program, 1989-98

	Policy scenario			
	Trigger price policy		Dairy termination program	
	Non-adopter	bST adopter	Non-adopter	bST adopter
52-cow farm:				
Probability of survival (percent)	100.0	100.0	100.0	100.0
Probability of success (percent)	99.0	100.0	100.0	100.0
Probability of increasing equity (percent)	0.0	0.0	3.0	7.0
Net present value ($1,000)	149.8	167.6	245.5	265.1
Present value of ending net worth ($1,000)	194.1	210.0	277.6	294.4
Present value of ending net worth as a percent of beginning net worth (percent)	52.4	56.7	74.9	79.4
Average annual net cash farm income ($1,000)	2.3	5.0	15.4	18.6
200-cow farm:				
Probability of survival (percent)	98.0	99.0	100.0	100.0
Probability of success (percent)	91.0	94.0	100.0	100.0
Probability of increasing equity (percent)	9.0	17.0	55.0	68.0
Net present value ($1,000)	352.2	438.8	733.8	819.5
Present value of ending net worth ($1,000)	542.9	618.4	871.6	944.5
Present value of ending net worth as a percent of beginning net worth (percent)	64.5	73.5	103.6	112.3
Average annual net cash farm income ($1,000)	27.4	40.2	82.5	97.8

SOURCE: Office of Technology Assessment, 1991.

Table C-16—Effects of a Large Reduction in Milk Demand on Representative Southwest Dairy Farms Who Adopt and Fail To Adopt bST, Given a Trigger Price and a Dairy Termination Program, 1989-98

	Policy scenario			
	Trigger price policy		Dairy termination program	
	Non-adopter	bST adopter	Non-adopter	bST adopter
350-cow farm:				
Probability of survival (percent)	52.0	69.0	100.0	100.0
Probability of success (percent)	52.0	69.0	100.0	100.0
Probability of increasing equity (percent)	6.0	11.0	91.0	95.0
Net present value ($1,000)	70.2	233.2	1,104.0	1,094.9
Present value of ending net worth ($1,000)	98.9	236.5	984.3	1,094.9
Present value of ending net worth as a percent of beginning net worth (percent)	15.4	36.9	153.7	170.9
Average annual net cash farm income ($1,000)	17.6	34.7	158.8	184.2
1,500-cow farm:				
Probability of survival (percent)	98.0	100.0	100.0	100.0
Probability of success (percent)	96.0	98.0	100.0	100.0
Probability of increasing equity (percent)	53.0	70.0	100.0	100.0
Net present value ($1,000)	1,820.4	2,268.0	5,241.5	5,735.8
Present value of ending net worth ($1,000)	2,278.4	2,671.1	5,263.1	5,693.9
Present value of ending net worth as a percent of beginning net worth (percent)	102.5	120.2	236.8	256.2
Average annual net cash farm income ($1,000)	282.7	360.2	882.1	967.4

SOURCE: Office of Technology Assessment, 1991.

Table C-17—Effects of a Large Reduction in Milk Demand on Representative Southeast Dairy Farms Who Adopt and Fail To Adopt bST, Given a Trigger Price and a Dairy Termination Program, 1989-98

	Policy scenario			
	Trigger price policy		Dairy termination program	
	Non-adopter	bST adopter	Non-adopter	bST adopter
200-cow farm:				
Probability of survival (percent)	88.0	94.0	100.0	100.0
Probability of success (percent)	51.0	80.0	100.0	100.0
Probability of increasing equity (percent)	0.0	1.0	45.0	68.0
Net present value ($1,000)	8.0	147.2	703.1	837.4
Present value of ending net worth ($1,000)	321.5	444.2	938.7	1,054.1
Present value of ending net worth as a percent of beginning net worth (percent)	33.4	46.1	97.5	109.5
Average annual net cash farm income ($1,000)	–42.7	–25.1	50.8	73.1
1,500-cow farm:				
Probability of survival (percent)	100.0	100.0	100.0	100.0
Probability of success (percent)	89.0	99.0	100.0	100.0
Probability of increasing equity (percent)	19.0	50.0	99.0	100.0
Net present value ($1,000)	1,689.1	2,562.2	5,470.5	6,459.4
Present value of ending net worth ($1,000)	3,633.2	4,390.7	6,946.5	7,798.4
Present value of ending net worth as a percent of beginning net worth (percent)	79.7	96.3	152.3	171.0
Average annual net cash farm income ($1,000)	200.2	343.8	867.7	1,040.4

SOURCE: Office of Technology Assessment, 1991.

Appendix D

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